THREE ESSAYS ON U.S. AGRICULTURE UNDER CLIMATE CHANGE: ACTIVE ENGAGEMENT IN MITIGATION AND ADAPTATION

A Dissertation

by

YUQUAN ZHANG

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

December 2011

Major Subject: Agricultural Economics

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Approved by:

Chair of Committee,	Bruce A. McCarl
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ABSTRACT

Three Essays on U.S. Agriculture under Climate Change: Active Engagement in Mitigation and Adaptation. (December 2011)

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Chair of Advisory Committee: Dr. Bruce A. McCarl

This dissertation investigates: (1) the implications of including high-yielding energy sorghum under the Renewable Fuels Standard (RFS2) program; (2) the effects of RFS2 with and without projected climate change scenarios on U.S. agriculture; (3) the spatial distribution of cattle breeders in Texas to quantify how climate factors influence cattle breed selection.

In the RFS2 energy sorghum work, the ability of the agriculture sector to meet the fuel requirements of RFS2 is examined with and without energy sorghum being a possibility using an agricultural sector model. The results show that energy sorghum would be a valuable contributor that would be used as a feedstock producing over 13 billion gallons per year of cellulosic ethanol. Without the presence of energy sorghum it is found that switchgrass serves as the major cellulosic ethanol feedstock. Findings also indicate that the presence of high-yielding energy sorghum does relax commodity prices and export reductions except for grain sorghum as energy sorghum competes with grain sorghum production. In addition, the results show that the introduction of energy sorghum has minimal effects on GHG mitigation potential in the agricultural sector.

In the RFS2 and climate change research, the analysis shows that climate change eases the burden of meeting the RFS2 mandates increasing consumer welfare while decreasing producer welfare. The results also show that climate change encourages a more diversified use of biofuel feedstocks for cellulosic ethanol production, in particular crop residues.

In the cattle breed research, summer heat stress is found to be a significant factor for breed selection: positive for *Bos indicus* and negative for *Bos taurus* and composite breeds. The estimation results also indicate a price-driven trade-off between *Bos taurus* and *Bos indicus* breeds.

DEDICATION

To my beloved mother, father and elder sister.

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CHAPTER I

INTRODUCTION

Global atmospheric concentrations of carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) – three prevalent greenhouse gases (GHG) – have increased markedly since 1750 as a result of human activities (IPCC WGI 2007). The increases in CO_2 emissions are primarily due to fossil fuel use and land use change, whereas much of the CH_4 and N_2O emissions come from the agricultural sector (IPCC WGI 2007). A relationship between observed global climate change and increased atmospheric GHG concentrations has been suggested by accumulating evidence – in fact the Intergovernmental Panel on Climate Change (IPCC) states that “most of the observed increase in global average temperatures since the mid-20th century is very likely (>90%) due to the observed increase in anthropogenic greenhouse gas concentrations.” (IPCC WGI 2007)

The recent U.S. GHG inventory data indicates that the agriculture-sourced GHG emissions accounted for about 7% of total U.S. GHG emissions (USDA 2008). Despite the relatively small role in GHG inventory, agriculture is frequently discussed in the context of climate change (Siikamäki and Maher 2010). Possible reasons may include that agriculture is among the economic sectors that may be strongly affected by climate change and that the agricultural sector has the potential to provide cost-competitive GHG mitigation options.

This dissertation follows the style of *American Journal of Agricultural Economics*.

Although it remains unclear whether an economy-wide GHG regulation would be implemented or not, the U.S. agricultural sector has been active in taking measures that contribute to climate change mitigation and adaptation, as demonstrated in part by the rapid expansion of biofuels production since the early 2000s.

Key legislative drivers of the biofuels expansion include the Energy Policy Act of 2005 (EPACT – also known as RFS1), the Energy Independence and Security Act of 2007 (EISA), and the 2002 and 2008 Farm Bills (Koshel and Rapporteurs 2010). RFS1 set numerical goals requiring 7.5 billion gallons per year (BGY) of renewable fuels to be produced by 2012. The Renewable Fuels Standard (RFS2) under EISA increased the mandate level further to 36 BGY by 2022, where 21 BGY are to be derived from cellulosic and other advanced sources.

While the biofuels expansion has been largely driven by EISA energy security concerns and increasing oil prices, an inherent agenda regarding climate change mitigation has also contributed to the growth of this industry. The renewable fuels provision – RFS2 – under EISA modified the definition of renewable fuels by setting and specifying minimum life-cycle GHG reduction rates for each type of renewable fuel (Koshel and Rapporteurs 2010). According to the U.S. Environmental Protection Agency (EPA), to be classified as "advanced biofuel", the GHG reduction threshold of 50% must be met. For "cellulosic biofuel", a 60% reduction rate is required.

The ambitious goal of RFS2 plus a relatively short implementation schedule presents production and logistical challenges for the biofuel industry. Problems can arise from the availability of biofuel feedstocks, in particular cellulosic ones, and activities of harvesting, storing, and transporting the feedstocks (EPA 2010). Also, the implications of the large-scale biofuels production go beyond GHG emissions reduction and energy security – it can transform agriculture and the food sector as a whole (Siikamäki and Maher 2010). Making sense of the significant role that RFS2 will probably play requires a comprehensive understanding of various aspects both within and beyond the boundary of the RFS2 program.

Though mitigation efforts are being made in agriculture and other sectors worldwide to reduce GHG emissions, global climate change in the coming decades appears however inevitable. Assuming the concentrations of all GHGs and aerosols are kept constant at year 2000 levels, a warming of about 0.1 °C per decade would still occur due the inertia of the climate system to reach stabilization (IPCC WGI 2007), let alone that the economic system is unlikely to reduce GHG emissions in the foreseeable future given projected socioeconomic growth and sluggishness in shifting the energy system (Rose and McCarl 2008). Given this background, climate change is very likely one of the forces to which U.S. agriculture will have to adapt to in the future (Reilly et al. 2001).

History shows that U.S. agriculture has been a system that has changed rapidly and continually since the European colonization (Reilly et al. 2001). Actually agricultural producers routinely make land use and management adjustments to deal with variability in climate, soil, market, and other factors. Also, non-climate factors such as changes in production technology, introduction of new crop varieties, and government farm programs can result in production patterns adjustments that better accommodate such conditions – for example, the northward shifts of maize and soybean production that occurred during the period of 1870 to 1990 (Reilly et al. 2003; Rosenberg 1992). Likewise, the introduction of RFS2 may alter production patterns in the agricultural sector, leading to different outcomes than what climate change forces alone would deliver. An understanding of how the U.S. agricultural sector would respond to a mixture of climate change and revisions in policies may help decision makers develop adaptation policies and producers make management decisions, keeping U.S. agriculture in a resilient and healthy status.

Production patterns may also change in the livestock sector – for example, with changes in cattle breeds, stocking rates or species mixes (Mu and McCarl 2011; Seo, McCarl and Mendelsohn 2010). Typically, the Southwest U.S. has been a place accommodating heat-tolerant cattle breeds such as Brangus that has *Bos indicus* traits, while the northern U.S. keeps the tradition of raising European-originated breeds that are more popular for beef production. Under climate change, cow-calf producers may turn to breeds that are more adapted to changed climates – a warming climate thus can imply a northward migration of “southern” cattle breeds. The knowledge of climate change’s regionally differentiated impacts on livestock breed adoption could help producers, and perhaps those on the supply chain, make better-informed decisions about breed selection and marketing practices for the future.

Collectively, this dissertation aims to forecast the outcomes of, and whenever possible, develop a detailed description of U.S. agriculture’s ongoing involvement in climate change mitigation and adaptation, providing insights for informed policy making and production decision-making. This is done through three essays.

- The first essay examines how the introduction of energy sorghum – a high yielding energy crop – under RFS2 impacts U.S. agriculture, in terms of biofuel delivery potential, grain crops prices and production levels, and GHG mitigation.
- The second essay explores the implications of climate change, in conjunction with an unfolding RFS2, for U.S. agriculture.
- The third essay investigates the climate effects on beef cattle breed selection in Texas – the primary center of the U.S. livestock industry – by examining the spatial allocation of cattle breeders raising major breeds to see if breed switches are a likely a climate change adaptation strategy.

CHAPTER II

HIGH BIOMASS ENERGY CROPS AS BIOFUEL FEEDSTOCKS: EFFECTS ON U.S. AGRICULTURAL ECONOMY AND GHG OFFSETS[1]

The biofuel industry in the U.S. has experienced a rapid expansion since the early 2000s. Fuel ethanol production levels have been growing rapidly with an over eight-fold increase from 1.6 BGY in 2000 to 13 BGY in 2010 (Renewable Fuels Association 2011). This growth has largely involved starch- and sugar-based first generation biofuels mainly from corn, and has raised concerns regarding its food price, energy balance and environmental effects (Abbott, Hurt and Tyner 2009; Boddiger 2007). In particular,

- the scaling up of biofuels production has contributed to rising food prices in the second half of the 2000s at home and abroad, diverting cereal production from human and livestock uses (Headey and Fan 2008; Mitchell 2008);
- the effect on export markets has been argued as a force fueling overseas deforestation, potentially resulting in considerable carbon emissions and substantial carbon debts (Fargione et al. 2008; Searchinger et al. 2008).

Besides, ethanol production is criticized as fossil energy-intensive delivering negative net energy (Pimentel and Patzek 2005), though some more recent analysis suggests otherwise (Farrell et al. 2006; Shapouri et al. 2008). In sum, these factors undermine

[1]This essay expands on Y.W. Zhang, R.A. Aisabokhae, and B.A. McCarl, “Energy Sorghum as A Biofuel Feedstock: Effects on GHG Offsets and Sector Performance” (poster presented at the 2010 AAEA, CAES & WAEA Joint Annual Meeting, Denver, Colorado, July 25 – 27, 2010), available at http://purl.umn.edu/61770.

the legitimacy of adopting biofuels as a strategy for climate change mitigation and perhaps as a strategy for enhancing U.S. energy security.

In response, the second generation biofuels that use cellulosic, non-food feedstocks have been advocated as future renewable fuel alternatives (Farrell et al. 2006; Koshel and Rapporteurs 2010; Ugarte, English and Jensen 2007), even though they would still divert land – such as to utilize the Conservation Reserve Program (CRP) land, to displace cropland pasture, and to reallocate existing cropland (USDOE and USDA 2005) for biomass feedstock production – and thus have export implications. Recently a number of high production volume crops like energy sorghum and miscanthus have been posed as high volume energy crops (McCutchen, Jr. and Baltensperger 2008; Rooney et al. 2007; Sanderson and Adler 2008), where advocates argue that they can help alleviate the issue of indirect land use change since they require fewer acres than many alternatives to produce a given volume of biofuels. The research presented in this essay investigates the impacts of heavy yield second generation biofuel feedstock crops' participation in RFS2 provisions on U.S. agriculture. We will focus on energy sorghum in particular. The analysis will examine fuel ethanol production, food and feed crop prices and production levels, and GHG mitigation potential.

The rest of this essay is organized as follows. In the literature review section, recent studies evaluating the effects of RFS2 or simply the biofuels production on U.S. agriculture are visited. Meanwhile, the appropriateness and the feasibility of using partial equilibrium models for the purpose of this study are discussed. Then in the methodology section, a brief overview of the Forest and Agricultural Sector Optimization Model with

Greenhouse Gases (FASOMGHG) and the modification to it for this study are presented. After that, major data inputs, scenarios employed, and model results are displayed and discussed. Finally this essay concludes.

Literature Review

EISA set numerical goals in its RFS2 provisions requiring 36 BGY of renewable fuels to be produced by 2022, where 21 BGY are to be obtained from cellulosic and other advanced sources. The ambitious goal of RFS2 together with a relatively short implementation schedule presents production and logistic challenges for the U.S. biofuel industry. Problems can arise from various aspects, including but not limited to the availability of biofuel feedstocks, resource competition, and commodity prices, along with logistical matters such as harvesting, storing, and transporting large volumes of biofuel feedstocks (EPA, 2010). Also, large-scale biofuels production is likely to transform U.S. agriculture in ways that influence not only energy production, but also food production and prices plus GHG emissions (Siikamäki and Maher 2010).

Partial and general equilibrium models have been used to evaluate the impacts of biofuel policies in Europe (Witzke et al. 2008) and the U.S. (Beach and McCarl 2010; Campiche, Bryant and Richardson 2010; Dixon, Osborne and Rimmer 2007). The inclusion of a biofuel sector in partial or general equilibrium models has been implemented with different levels of specifications of bioenergy production activities.

Typically, the computable general equilibrium (CGE) approach allows the analysis of policies on the entire economy, including fossil fuel energy markets. Dixon et al. (2007) used USAGE to investigate the economy-wide effects of EISA. As introduced in their article, USAGE is a dynamic CGE model covering 500 industries and has considerably-detailed U.S. energy market representations. Their results suggest that the substitution of biomass for crude petroleum has a noticeable damping effect on world demand for crude petroleum, generating a 4.8% decrease in crude petroleum price by 2020. And, they find that the biomass-induced expansion of crop production imposes positive effects on industries providing agricultural production inputs, including farm machinery, fertilizers, and cordage and twine.

More recently, the global general equilibrium model Global Trade Analysis Project (GTAP) was modified by Campiche, Bryant and Richardson (2010) to explore the long-run effects of decreasing cellulosic ethanol production costs on U.S. agricultural economy, in the absence of EISA however. This research points out that the presence of cellulose-to-biofuel conversion technology could exacerbate, rather than relieve, the competition between food and fuel uses among crops. Meanwhile, the U.S. would import less crude oil than otherwise. Earlier, the GTAP-BIO model was employed by Keeney and Hertel (2009) to examine the worldwide indirect land use impacts of the U.S. biofuel policy. This study imposed a nested constant elasticity of transformation structure on crops production and elicited land supply responses for a moderate 1 BGY biofuel volume increase. Their results show that the cropland cover in the U.S. would increase by 0.10%, whereas the pasture land and the forest cover decrease by -0.35 and -

0.53% respectively. In addition, agricultural exporters would respond by expanding cropland at the expense of forest and pasture.

The preceding studies using CGE models in general find that the expansion of conventional and cellulosic ethanol production in the U.S. has broad impacts going beyond the agricultural sector – other industries, export and import markets can be significantly influenced as well. In fact, current fuel ethanol market developments and policy changes are found to be able to alter the nature and strength of the links between energy and agricultural markets (Thompson, Meyer and Westhoff 2009). As stated in Thompson, Meyer and Westhoff (2009), "biofuels present a new mechanism of price transmission." These findings lend support to the use of CGE models for the RFS2 effects study.

However, the degree of aggregation used within current CGE models allows lower levels of market and production representations than is contained in many agriculturally-focused partial equilibrium models. Generally, agriculturally-focused partial equilibrium models have geographically disaggregated physical and market representations of crop and livestock production plus secondary commodities processing. These production possibilities are then modeled to interact in a competitive market with or without policy interventions. Such a detailed approach enables a closer examination of policy effects on the agricultural sector.

Ugarte, English and Jensen (2007) expanded POLYSYS – a dynamic and complex partial equilibrium model for the U.S. agricultural sector – and integrated it with modified IMPLAN – an economic input and output model – to study the economic impacts of the U.S. biofuels expansion. Assuming a scenario of producing 60 BGY of biofuels by 2030, they find that the introduction of cellulose-to-ethanol technology noticeably reduces positive pressure on corn prices and releases cropland for soybeans production, consistent with findings in Campiche, Bryant and Richardson (2010). Earlier, Walsh et al. (2003) analyzed the impacts of large-scale bioenergy crop production in the U.S. using modified POLYSYS also. They find that, in the absence of cellulose-based ethanol production possibility, traditional crops prices would increase and the increments are sensitive to price and acreage assumptions about bioenergy crops.

Searchinger et al. (2008) employed a less detailed, yet still complicated global agricultural model to project changes in cropland acreage of major crops by country or region, under the scenario that additional 15 BGY of corn ethanol above projected levels will be produced in the U.S. by 2016. The outcome, as shown in their findings, is significant displacements of non-corn croplands worldwide. They further conclude that land use change, triggered by higher biofuel feedstock prices, can result in large carbon debts instead of carbon savings.

For the most part, the partial equilibrium models employed in studies reviewed above excel in the explicit specifications of agricultural economy, though they typically do not fully take into consideration the aforementioned “strengthened” links between energy and agricultural markets as argued in Thompson, Meyer and Westhoff (2009) when biofuels production becomes active. A remedy could be introducing energy prices generated by outside CGE models into partial equilibrium models to “generalize” the agriculturally-focused partial equilibrium model.

Note that the studies mentioned above, especially the ones using CGE models, typically introduce moderate-size shocks into the model they use, rather than including the large-scale RFS2 volume mandates by 2022. For example, in Keeney and Hertel (2009) the perturbation is a 1 BGY biofuel volume increase; in Searchinger et al. (2008) it is 56 billion liters of biofuels, equivalent to 15 BGY; and in Thompson et al. (2009) it is 15 BGY by 2014. No RFS2 mandates are incorporated in Campiche et al. (2010).

Theoretically, CGE models in which demand and supply are governed by nested constant elasticity of substitution structures can accommodate marginal changes only. Large shocks may deliver results that are out of context – as pointed out in Searchinger et al. (2008), "far larger biofuel increases could change the magnitude of results in unclear ways that would require modifications to the model." Given above, it may be wise to admit moderate shocks only to CGE models when investigating biofuel policy effects. The magnitude of the threshold for a "marginal" shock is nonetheless difficult to define. However, the finding that corn ethanol would peak around 15 BGY (Tyner 2008) plus the empirical uses of 15 BGY in the aforementioned literature may lend support to using 15 BGY as the maximum threshold for traditional ethanol production, which is largely corn-based. Moreover, this 15 BGY of conventional biofuels production is in nature more of a demand-driven shock than a supply deviation imposing on the agricultural sector.

Although the RFS2 mandates on cellulosic ethanol represent a demand shock, the introduction of energy crop production together with cellulose-to-ethanol technology potentially expands the supply. Besides, recall that partial equilibrium models focusing on agriculture typically have detailed and highly disaggregated production specifications – thereby a more accurate supply representation. The “marginal” shock of cellulosic ethanol requirement thus may not be as disruptive when using a partial equilibrium model, as the demand-side shock may be partially offset by the supply-side expansion.

Most recently, Beach and McCarl (2010) used FASOMGHG to evaluate RFS2 impacts on the U.S. agricultural and forestry sector, in which switchgrass is modeled as the principal designated energy crop. The research presented in this essay extends their work by incorporating high-yielding energy crop – energy sorghum – into FASOMGHG to explore the implications of second generation biofuel feedstocks for U.S. agricultural economy.

Methodology

As introduced earlier, the utilization of high-yielding energy crops under RFS2 can arguably alleviate the indirect land use change issue (assuming the RFS2 mandates are binding), since less land area may be required for biofuel feedstocks production. This effect on overall cropland usage can be illustrated by Figure II-1 below.

In Figure II-1, from left to right, S_1 denotes the cropland supply from CRP land, S_2 the supply from the U.S. cropland base including conventional cropland and cropland pasture, and S the aggregate supply combining S_1 and S_2. Note that an upper limit is set for the CRP-based cropland supply S_1 in accordance with the 2008 Farm Bill. The overall demand for cropland (including both conventional crops and energy crops) under

RFS2 is denoted by *D*. And D^h, to the left of *D*, represents an expected lower level of overall demand for cropland under the high-yielding energy crops scenario. Meanwhile, S^h_2 denotes a potentially reduced supply from the cropland base, as more cropland and/or cropland pasture may be allocated toward other uses when the overall demand for cropland decreases.

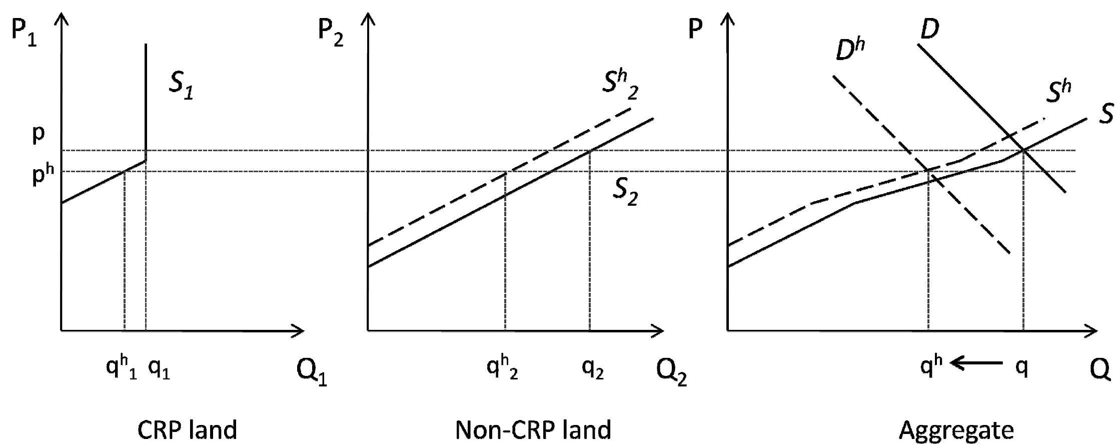


Figure II-1 Expected effects of introducing high-yielding energy crops on cropland usage and CRP land reversion under RFS2.

As demonstrated in the figure, compared to *D*, D^h results in smaller CRP land reversion to cropland ($q^h_1 < q_1$) and less usage of the cropland base ($q^h_2 < q_2$) for conventional and energy crops production. Accompanying the lower level of demand is an expected decrease in cropland price ($p^h < p$).

FASOMGHG Overview

The agricultural component of FASOMGHG is employed for this research to model the agricultural land competition mentioned above. FASOMGHG is a dynamic, nonlinear, and price endogenous programming model for the forest and agricultural sectors in the conterminous U.S. (the “lower 48 states”) plus export markets. It simulates the allocation of land over time to competing activities in the forest and agricultural sectors, suggesting consequences for the markets of commodities supplied by these lands (Adams et al. 2005). In EPA (2010), both FASOMGHG and FAPRI have been used for the regulatory impact analysis of RFS2. Besides, as an explicitly detailed partial equilibrium model, FASOMGHG takes energy prices as exogenous – in this research, the Annual Energy Outlook 2009 (AEO) data from the U.S. Energy Information Administration (EIA) are used.

Regarding agricultural production, the way that FASOMGHG specifies crops production is heavily agronomy-oriented and spatially disaggregated. For economic agents – the sub-region level producers with various enterprises, land is more of a Leontief component that needs to be competed for. This bottom-up approach of production representation allows a resilient supply that can accommodate shocks on the macro level. Also, in FASOMGHG the resultant crop mix is required to fall in the convex space built by the past 20 years’ crop mixes (Adams et al. 2005). Thereupon the aggregate supply is micro-theoretically and empirically determined.

Regarding GHG accounting, FASOMGHG estimates CO_2, CH_4, and N_2O emitted from and sequestered by the agricultural and forest sectors. For the agricultural sector, the GHG accounting includes emission/mitigation activities such as soil tillage change, land conversion, fertilizer usage change, fossil fuel usage change, and livestock and manure management. Also, FASOMGHG accounts for GHG emissions and/or offsets from sources that are directly related to agriculture – such as fertilizer production and biofuel-based offsets. More detailed documentation of GHG accounting in FASOMGHG can be found in Adams et al. (2005).

The mathematical structure of FASOMGHG, adapted from Adams et al. (2005), is presented below.

$$(2.1)\quad \max \quad \sum_t \{[\sum_h \int_0^{Z_{ht}} P_{dht}(Z_{ht})dZ_{ht} - \sum_i \int_0^{X_{it}} P_{sit}(X_{it})dX_{it}](\frac{1}{1+r})^t\}$$

$$(2.2)\quad s.t. \quad Z_{ht} - \sum_\beta \sum_k c_{h\beta kt} Q_{\beta kt} \le 0, \quad \forall h,t$$

$$(2.3)\quad - X_{it} + \sum_\beta \sum_k a_{i\beta kt} Q_{\beta kt} \le 0, \quad \forall i,t$$

$$(2.4)\quad \sum_k b_{j\beta kt} Q_{\beta kt} \le Y_{j\beta t}, \forall j,\beta,t$$

$$(2.5)\quad Z_{ht}, \quad X_{it}, \quad Q_{\beta kt} \ge 0, \quad \forall i,h,\beta,k,t$$

where

h indexes commodities including primary (e.g. corn) and secondary (e.g. ethanol) ones, *i* purchased inputs, *j* resources, *k* production processes, and *β* firms;

Z_h presents the quantities of commodities traded on market;

$Q_{\beta k}$ indicates the levels of production processes;

X_i refers to the amounts of purchased input factors;

$Y_{j\beta}$ represents the resource endowments.

Besides, $c_{h\beta k}$ describes the output yield *h* for production processes *Q*, which are firm and process-specific; $a_{i\beta k}$ depicts the inputs usage associated with production processes *Q*; $b_{j\beta k}$ illustrates the resources utilized by production processes *Q*. These three coefficients help set the quantitative relationships between production processes *Q* and commodities *h*, purchase inputs *X*, and resources endowments *Y* in equations (2.2), (2.3), and (2.4), respectively. A year index *t* is also applied to the mathematical structure and *r* is the discount rate.

Last but not the least, equation (2.1) outlines the objective of maximizing the net present value of aggregate consumer and producer welfare over time measured by the areas underneath the demand curves P_d and above the supply curves P_s.

Modifications to FASOMGHG

In Beach and McCarl (2010), FASOMGHG was expanded to include RFS2 renewable fuels production requirements. In mathematical terms, they can be expressed:

(2.6) $$Z_{h^*t} \geq M_{h^*t}, \ \forall h^*, t$$

(2.7) $$Z_{h^*t} \leq M_{h^*t}, \ \forall h^*, t$$

where h^* primarily includes grain-based and cellulosic ethanol, and *M* represents the projected or mandated volumes. In principle, equations (2.6) and (2.7) set the upper and lower limits for renewable fuels production. Moreover, the prices for cellulosic ethanol, $P_{dt}(Z_{h^*t})$, are set according to the AEO 2009 projections mentioned above. Thus by specifying RFS2 in this way, we are assuming that the RFS2 demand for renewable fuels is exogenous to the modeled conterminous “lower 48 states” U.S. agricultural sector (the

U.S. agricultural sector henceforth for brevity). What the U.S. agricultural sector will do is to respond to RFS2 by determining what kind(s) of biofuel feedstocks will be used and by how much.

To conduct the study of high biomass volume energy crops, the set of production processes Q also needs to be expanded to include production possibilities of growing high-yielding energy crops in appropriate regions, and cellulosic ethanol production processes utilizing high-yielding energy crops as feedstocks. In brief, the modification procedure involves the inclusion of crop budgets and biofuel processing budgets related to high-yielding energy crops. The research presented in this study will focus on energy sorghum as the designated high-yielding energy crop.

An additional note here is that FASOMGHG does not explicitly model the RFS2 compliance mechanism but takes the compliance with RFS2 mandates as given. In the real world, Renewable Identification Numbers (RINs) are used to ensure that the RFS2 mandates are met. As discussed in Thompson, Meyer and Westhoff (2010), the government firstly issues RINs to renewable fuel producers based on the amount and the type of renewable fuels produced, and then renewable fuel producers sell their products in conjunction with RINs to fuel blenders – the obligated parties under RFS2; fuel blenders will then show proof of RINs to the government on an annual basis, and the government verifies that there are sufficient RINs submitted by fuel blenders to meet the RFS2 mandates. Moreover, the RINs are tradable among fuel blenders, and rollover of RINs for stock-holding is allowed. However, there are strict conditions imposed on using stocked RINs for compliance, and thus the RIN trading scheme still encourages a sustained year-by-year compliance. More information about the RFS2 compliance mechanism can be found in Thompson, Meyer and Westhoff (2010). In FASOMGHG, the U.S. agricultural sector is modeled on a 5-year time step, so are the RFS2 volume requirements. The potential nuanced yearly variation in renewable fuels production thus may be reasonably ignored for simplification of the RFS2 assumptions.

Data

As mentioned in the introduction, this research highlights energy sorghum as the designated high-yielding energy crop. Energy sorghum crop budgets were constructed based on the Texas AgriLife Extension experiment data. The College Station-based data were provided by Dr. John Mullet, a professor of biochemistry and biophysics at Texas A&M University.

In principle, energy sorghum has a virtually identical crop budget as grain sorghum except the yield, as energy sorghum production focuses on maximizing harvestable biomass such as stalks whereas grain sorghum production emphasizes delivering feed grains. Nonetheless, the College Station (located in the Texas Central Blackland sub-region as defined in FASOMGHG) -based ratio of energy sorghum biomass yield to grain sorghum yield is employed to generate energy sorghum crop budgets for FASOMGHG production regions where applicable.

Table II–1 Energy Sorghum Yield in Dry Tons per Acre by FASOMGHG Sub-Region and Irrigation Status, 2005 and 2030.

	State/Sub-region	*DryLand*		*Irrigated*	
		2005	2030	2005	2030
Corn Belt	Illinois North	17.84	18.25		
	Illinois South	23.33	23.86		
	Indiana North	13.34	13.65		
	Indiana South	21.65	22.15		
	Iowa West	13.34	13.65		
	Iowa Central	13.34	13.65		
	Iowa Northeast	13.34	13.65		
	Iowa South	20.90	21.38		
	Missouri	20.58	21.05		
Great Plains	Kansas	13.57	13.89	20.36	20.83
	Nebraska	18.39	18.81	23.21	23.74
	South Dakota	12.92	13.21		
Northeast	Delaware	17.08	17.47		
	Maryland	17.08	17.47		
	Pennsylvania	17.08	17.47		
Pacific Southwest	California North	11.08	11.33	29.46	30.13
	California South	15.11	15.45		
Rocky Mountains	Arizona			17.52	17.92
	Colorado	9.41	9.63	16.19	16.56
	New Mexico	10.83	11.07	9.85	10.08
South Central	Alabama	13.14	13.44		
	Arkansas	18.83	19.26		
	Kentucky	18.61	19.04		
	Louisiana	18.61	19.04		
	Mississippi	17.95	18.36		
	Tennessee	17.52	17.92		
	Texas East	14.87	15.21	15.87	16.24
Southeast	Georgia	10.51	10.75		
	North Carolina	15.33	15.68		
	South Carolina	14.23	14.56		
	Virginia	14.71	15.05		
Southwest	Oklahoma	9.02	9.22	19.37	19.81
	Texas High Plains	6.19	6.33	15.43	15.79
	Texas Rolling Plains	8.54	8.74	13.83	14.15
	Texas Central Blackland	15.75	16.11	22.24	22.75
	Texas Edward Plateau	9.63	9.85	19.91	20.37
	Texas Coastal Bend	15.74	16.10	21.70	22.19
	Texas South	8.97	9.18	15.14	15.49
	Texas Trans Pecos	7.01	7.17	14.89	15.23

Specifically, the ratio is used to adjust the output yields in grain sorghum crop budgets that are already included in the FASOMGHG database. Energy sorghum crop budgets for various FASOMGHG production regions are thereby obtained, with inputs identical to local grain sorghum crop budgets and output yield being derived from experiment data.

Table II-1 presents the derived dryland and irrigated energy sorghum biomass yield by FASOMGHG sub-region for the years 2005 and 2030. An annual yield growth rate of 0.09% – identical to that of grain sorghum as used in FASOMGHG – is assumed for energy sorghum production. The specific FASOMGHG region definitions can be found in Adams et al. (2005).

Table II–2 Region-Specific Switchgrass Yield in Dry Tons per Acre, 2005 and 2030.

Region	*Yield (2005)*	*Yield (2030)*
Corn Belt (CB)	7.46	9.33
Great Plains (GP)	4.55	5.69
Lake States (LS)	5.78	7.23
Northeast (NE)	4.00	5.00
Rocky Mountains (RM)	2.44	3.05
South Central (SC)	7.04	8.80
Southeast (SE)	6.07	7.59
Southwest (SW)	6.39	7.99

Switchgrass yields (under dryland conditions) in the FASOMGHG database are also presented in Table II-2 for comparison purpose. In general, the dryland energy sorghum yield is more than twice the yield of switchgrass. Moreover, we allow the irrigation option for energy sorghum production in FASOMGHG, as the substantially higher yields under irrigated conditions (Combs 2008) shown in Table II-1 warrant the relevance of including this production possibility.

The bioenergy processing budgets for energy sorghum were built based upon switchgrass bioenergy processing budgets included in the FASOMGHG database, considering that both switchgrass and energy sorghum are cellulosic feedstocks. As documented in Beach and McCarl (2010), a common cellulose-to-ethanol technology is applied to various kinds of cellulosic feedstocks including crop residues (e.g. corn residue), processing residues (e.g. sweet sorghum pulp), and dedicated energy crops (e.g. switchgrass), in addition to energy sorghum. By 2030, the conversion rate is assumed to be 92.3 gallons per dry ton of cellulosic feedstock, and the processing cost is assumed to be \$3.29 per gallon for all feedstocks except sweet sorghum pulp (\$1.39 per gallon) in the base period 2005. The processing costs are also assumed to decrease as technology advances. In addition to processing costs, hauling costs and storage costs are also considered – typically dedicated energy crops are assumed to incur less storage costs than crop residues due to their longer harvest windows. Adams et al. (2005), Beach and McCarl (2010) and Beach et al. (2010) provide more details and references about the biofuels processing. In principle, the economic returns to biofuel processors are a function of renewable fuel prices (AEO 2009 projections), feedstock prices, processing costs, hauling costs and storage costs.

Integrating the information above, this study employs the scenarios shown in Table II-3 to examine the implications of introducing high-yielding energy sorghum under RFS2.

Table II–3 Model Scenarios for High Volume Energy Crops Study.

Scenario	*RFS2 Mandates*	*Energy Sorghum*	*CRP Reversion*
No RFS2			√
RFS2 Switchgrass	√		√
RFS2 Energy Sorghum	√	√	√

Note that CRP land reversion to cropland is allowed in all scenarios – however, a minimum of 32 million acres of CRP land will be maintained in accordance with the 2008 Farm Bill. As for the RFS2 mandates representation, the model requires that at least 13.7 BGY of cellulosic ethanol are to be produced by 2022, and meanwhile the grain-based ethanol is constrained to be no more than 15 BGY, following the RFS2 assumptions in Beach and McCarl (2010) and EPA (2010). The total amount of ethanol listed above is less than the full 36 BGY, because in addition to agricultural sources, other materials such as municipal solid waste and algae are also expected to contribute to RFS2 (EPA 2010).

Model Results

Fuel Ethanol Production

Table II-4 compares the feedstock-specific ethanol production by 2030 across scenarios. Under the RFS2 Switchgrass scenario, a noticeably greater amount of grain-based ethanol is produced than under the No RFS2 scenario, hitting the ceiling volume specified in RFS2. Corn-based ethanol is estimated to be the primary contributor to this increment, indicating its competitiveness over other grain-based alternatives. As for cellulosic ethanol production, switchgrass dominates the feedstock supply, with bagasse, sweet sorghum pulp, willow and crop residues supplementing in order of declining volume. Compared to Beach and McCarl (2010), switchgrass has increased its role while corn residue decreases its contribution substantially in commensurate volume.

Note that the Beach and McCarl (2010) study models both the U.S. agricultural and forestry sectors in FASOMGHG whereas this research focuses on the agricultural sector only. Therefore land competition is reduced – potentially allowing more cropland to move into switchgrass production. Also, during the course of this work storage costs were introduced (Beach et al. 2010). As mentioned earlier, dedicated energy crops exhibit lower storage costs than do crop residues due to their assumed longer harvest windows. Thus switchgrass gains a further advantage in economic viability in this study.

Paying attention to the RFS2 Energy Sorghum scenario, we can find that energy sorghum replaces switchgrass and crop residues completely in providing cellulosic ethanol – up to over 13 BGY by 2030.

The results shown in Table II-4 suggests that the inclusion of high-yielding energy crops such as energy sorghum can significantly alter the feedstock mix for cellulosic ethanol production, and dedicated energy crops have the potential to play a major role in meeting RFS2 mandates.

Table II–4 Ethanol Production in Million Gallons per Year by Feedstock under Alternative Scenarios, 2030.

Feedstock	*No RFS2*	*RFS2 Switchgrass*	*RFS2 Energy Sorghum*
Cellulosic Ethanol			
Switchgrass	-	12,744	-
Willow	-	61	-
Energy Sorghum	-	-	13,023
Corn Residue	-	20	-
Wheat Residue	-	15	-
Rice Residue	-	6	-
Bagasse	250	735	663
Sweet Sorghum Pulp	-	106	-
Grain Ethanol			
Corn	13,544	14,985	14,985
Barley	23	-	30
Sweet Sorghum	-	30	-
Total	13,818	28,701	28,701

Table II-5 presents the geographical distribution of energy sorghum production in 2030. Note that in FASOMGHG, the biofuel feedstocks utilized by ethanol plants are assumed to be obtained locally (Beach and McCarl 2010). As we see, the majority of the energy sorghum production – and thus the processing of energy sorghum into cellulosic ethanol – is projected to take place in the Great Plains, Corn Belt and Southwest regions, though in this study FASOMGHG allows the possibilities of growing energy sorghum in most production sub-regions as indicated in Table II-1.

Table II–5 Energy Sorghum Acreage in Million Acres by Region and Irrigation Status, 2030.

Region	*Dryland*	*Irrigated*
Corn Belt	2.89	
Great Plains	3.34	0.52
Northeast	0.01	
Rocky Mountains	0.20	0.10
South Central	0.87	
Southeast	0.09	
Southwest	2.08	0.49
Total	9.48	1.10

Moreover, we find that the dryland acreage of energy sorghum is far greater than the irrigated acreage in all reported FASOMGHG regions, as shown in Table II-5. This dryland preference may suggest the relatively better dryland performance exhibited by energy sorghum relative to other crops and that economically, energy sorghum is less competitive as a user of water than other irrigated crops it seeks to displace, following the findings in Jain et al. (2010) which assesses the economical potential of bioenergy crop production. Furthermore, this dryland preference implies that little irrigation water use is associated with energy sorghum, thus enhancing the environmental friendliness of RFS2-induced energy sorghum ethanol production.

Crop Price, Production, and Export

Intuitively, the relatively high biomass yields associated with energy sorghum – compared to switchgrass and other grain crops – implies reduced land competition between food, feed and fuel crops production under RFS2, and consequently reduced price pressure on conventional grain crops and restoration of export levels. The model results presented in Table II-6 below confirm this expectation. As we see, compared to the RFS2 Switchgrass scenario, the crop price index under the RFS2 Energy Sorghum scenario is noticeably smaller, and the crop production and export indices increase, meeting the aforementioned expectation. Also, the livestock price index gets reduced and the production index gets larger under the RFS2 Energy Sorghum scenario, though the magnitudes of the changes are smaller than those for the crop indices.

Table II–6 Fisher Indices of Crop and Livestock Price, Production and Crop Export Relative to the No RFS2 Baseline (Base=100), 2030.

Scenario	*Conventional Crops*			*Livestock*	
	Price	Quantity	Export	Price	Quantity
RFS2 Switchgrass	105.6	98.6	92.1	101.0	98.6
RFS2 Energy Sorghum	102.9	100.5	96.0	100.3	99.9

A closer look into crop prices, production levels, and export volumes is provided also. Table II-7 shows that, under RFS2, the presence of high-yielding energy sorghum induces a considerably greater increment in grain sorghum price relative to the No RFS2 baseline than in the absence of energy sorghum. Correspondingly, in Table II-8, grain sorghum is shown to incur a greater reduction in its production level under the RFS2 Energy Sorghum scenario. Meanwhile, corn production sees a significantly greater increase. For wheat prices, the introduction of energy sorghum under RFS2 uniformly reduces the price pressure, and Table II-8 shows that in general, the presence of energy sorghum either expands or reduces the decrease in wheat production.

Table II–7 Selected Crop Prices ($ per Unit) under Alternative Scenarios, 2030.

Crop	*Unit*	*No RFS2*	*RFS2 Switchgrass*		*RFS2 Energy Sorghum*	
		baseline	level	change	level	change
Corn	bushel	3.04	3.24	6.41%	3.14	3.02%
Sorghum, Grain	cwt	6.00	6.23	3.83%	6.69	11.49%
Soybeans	bushel	9.17	9.84	7.33%	9.51	3.76%
Wheat, Soft White	bushel	5.77	6.21	7.61%	6.06	5.13%
Wheat, Hard Red Winter	bushel	4.33	4.62	6.55%	4.37	0.76%
Wheat, Hard Red Spring	bushel	4.56	4.78	4.65%	4.71	3.24%
Wheat, Soft Red Winter	bushel	4.42	4.71	6.40%	4.46	0.75%
Wheat, Durum	bushel	7.22	7.69	6.48%	7.39	2.34%

In sum, the price and production results for selected major crops suggest that the inclusion of high-yielding energy sorghum under RFS2 does not necessarily result in price alleviation for all crops but rather mixed outcomes. While the effects of RFS2 with energy sorghum on most major crops are projected to follow the expectation, grain sorghum results are an exception.

Table II–8 Selected Crop Production Levels in Million Units under Alternative Scenarios, 2030.

Crop	*Unit*	*No RFS2*	*RFS2 Switchgrass*		*RFS2 Energy Sorghum*	
		baseline	level	change	level	change
Corn	bushel	17,740	17,755	0.09%	18,390	3.66%
Sorghum, Grain	Cwt	274	251	-8.44%	92	-66.60%
Soybeans	bushel	3,292	3,207	-2.57%	3,310	0.57%
Wheat, Soft White	bushel	418	402	-3.84%	407	-2.72%
Wheat, Hard Red Winter	bushel	953	1,006	5.57%	1,037	8.83%
Wheat, Hard Red Spring	bushel	630	620	-1.50%	627	-0.37%
Wheat, Soft Red Winter	bushel	711	631	-11.29%	629	-11.56%
Wheat, Durum	bushel	213	137	-35.60%	125	-41.09%

Recall that energy sorghum is, as suggested in Table II-5, an energy crop primarily grown in the Great Plains region – the major production area for grain sorghum (USDA NASS 2007). Under RFS2, the agronomic similarities between grain and energy sorghum, together with the different profitability potentials associated with feed and fuel uses, may facilitate a virtually direct cropland competition between grain and energy sorghum. Given the mandatory nature of RFS2, it thus may not be surprising to see that energy sorghum production would expand largely at the expense of grain sorghum production, resulting in reduced grain sorghum production level and higher grain sorghum price. Also, recall that grain sorghum is primarily used for feed use. A reduction in grain sorghum production thus may dictate other feed crops to be grown and/or used to compensate for production reductions, should the demand for feed remain virtually unaltered. Table II-8 actually shows that corn production has expanded significantly – very likely to substitute for the displaced grain sorghum.

Table II–9 Selected Crop Exports in Million Units under Alternative Scenarios, 2030.

Crop	*Unit*	*No RFS2*	*RFS2 Switchgrass*		*RFS2 Energy Sorghum*	
		baseline	level	change	level	change
Corn	bushel	2,950	2,735	-7.29%	2,844	-3.60%
Sorghum, Grain	cwt	124	104	-16.41%	88	-29.47%
Soybeans	bushel	1,245	1,108	-11.02%	1,168	-6.20%
Wheat, Soft White	bushel	302	287	-4.85%	292	-3.40%
Wheat, Hard Red Winter	bushel	463	451	-2.52%	463	-0.04%
Wheat, Hard Red Spring	bushel	925	921	-0.51%	922	-0.34%
Wheat, Soft Red Winter	bushel	123	120	-2.22%	123	0.00%
Wheat, Durum	bushel	56	55	-1.50%	55	-0.72%

Table II-9 displays the export volumes for selected major crops in 2030 under alternative scenarios. The effects of including energy sorghum under RFS2 on exports of most selected crops meet the expectation that high yielding energy crops can alleviate the supply-demand tension for conventional crop export market. For example, the wheat export volumes are estimated to restore the No RFS2 level – compared to the RFS2 Switchgrass scenario. For grain sorghum, on the contrary, the inclusion of energy sorghum decreases its export volume further, corresponding to the aforementioned price increments in grain sorghum and the noteworthy reduction in grain sorghum production.

Land Use and GHG Mitigation Potential

As introduced earlier, indirect land use change induced by biofuel feedstock crop production is considered to have negative influence on biofuel-based GHG mitigation potential. For the agricultural sector, this may imply increased N_2O and CO_2 emissions due to increased utilization of existing cropland (e.g. more extensive use of fertilizer), as hypothesized in Searchinger et al. (2008). The introduction of high-yielding energy crops may slightly alleviate this effect, as illustrated in Figure II-2.

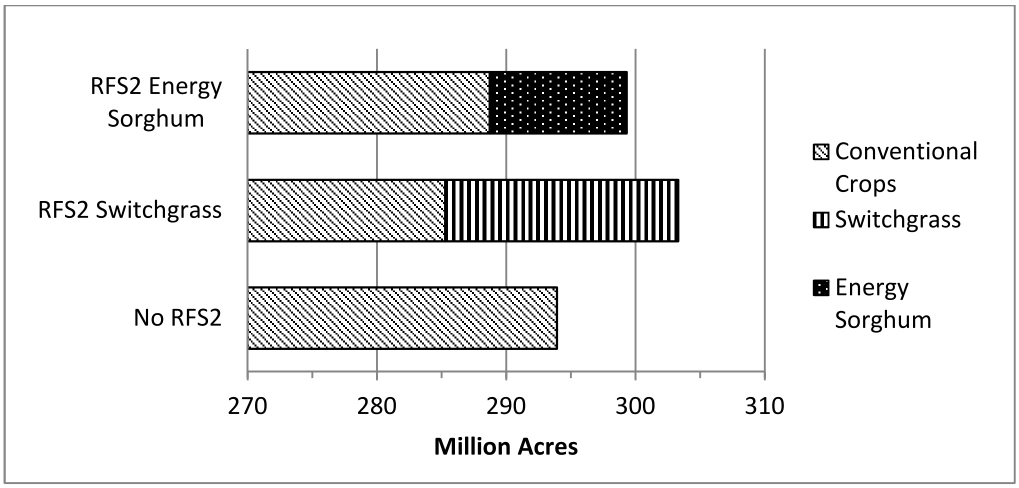


Figure II-2 Cropland usage under alternative scenarios, 2030.

Figure II-2 presents the acreages of energy crops versus conventional crops in 2030 under alternative scenarios. As we see, the RFS2 program increases the aggregate use of cropland for both conventional and energy crops production. With high-yielding energy sorghum, less cropland is projected to be devoted to energy crops and the overall cropland usage is reduced, meeting the expectation depicted in Figure II-1. The 2030 cropland price estimate is $94.46, $121.78 and $105.83 per acre under the No RFS2, RFS2 Switchgrass, and RFS2 Energy Sorghum scenario, respectively. The inclusion of energy sorghum thus decreases the cropland price, significantly.

The comparison of cropland acreage and allocation across the scenarios suggests that greater N_2O and CO_2 emissions may occur under RFS2. The effects of the inclusion of energy sorghum on GHG mitigation potential may be however indefinite. Consider, on the one hand, energy sorghum reduces the demand for cropland and thereby decrease GHG emissions from crop production; on the other hand, energy sorghum production requires greater inputs per acre of cropland than switchgrass (in FASOMGHG energy sorghum uses grain sorghum crop budget whereas switchgrass is assumed to be a much less managed energy crop), thus offsetting its contribution to GHG mitigation at least partially.

Figure II-3 shows the land use change between cropland, cropland pasture and CRP land under alternative scenarios. The positive part indicates land transferring into cropland, whereas the negative denotes cropland transferring out to other land uses. Under RFS2, rising cropland demand causes some cropland pasture to be converted to cropland and a greater amount of CRP land to revert back to cropland. The reduced cropland conversion (till the opposite) to cropland pasture implies a decrease in N_2O emissions, as less livestock production may follow. It also reflects increased opportunity cost of cropland conversion to other land uses under RFS2, as cropland price increases ($121.78 per acre). The presence of energy sorghum releases some cropland for cropland pasture use however, implying an increase in N_2O emissions due to potentially more livestock production activities, and reflecting a less intense land use competition with a lower cropland price ($105.83 per acre).

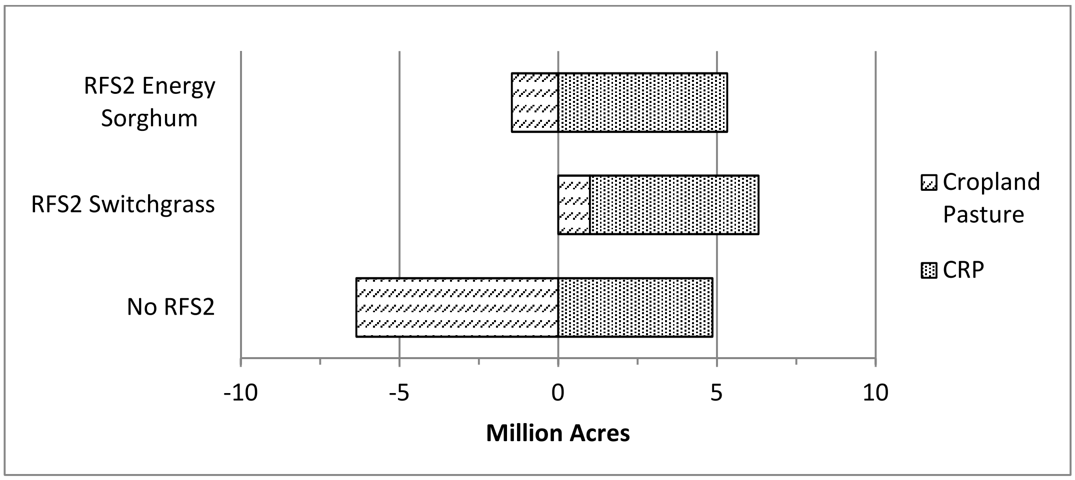


Figure II-3 Land use change under alternative scenarios, 2030.

Also noticeable is that the inclusion of energy sorghum results in CRP land reversion in the same size as under the RFS2 Switchgrass scenario. Actually 5.3 million acres is the upper limit for CRP land reversion because we assume that at least 32 million acres of CRP land will be maintained following the 2008 Farm Bill.

In sum, based on Figure II-3, RFS2 may decrease N_2O emissions mainly through reducing cropland conversion to cropland pasture. The inclusion of energy sorghum may however do the opposite.

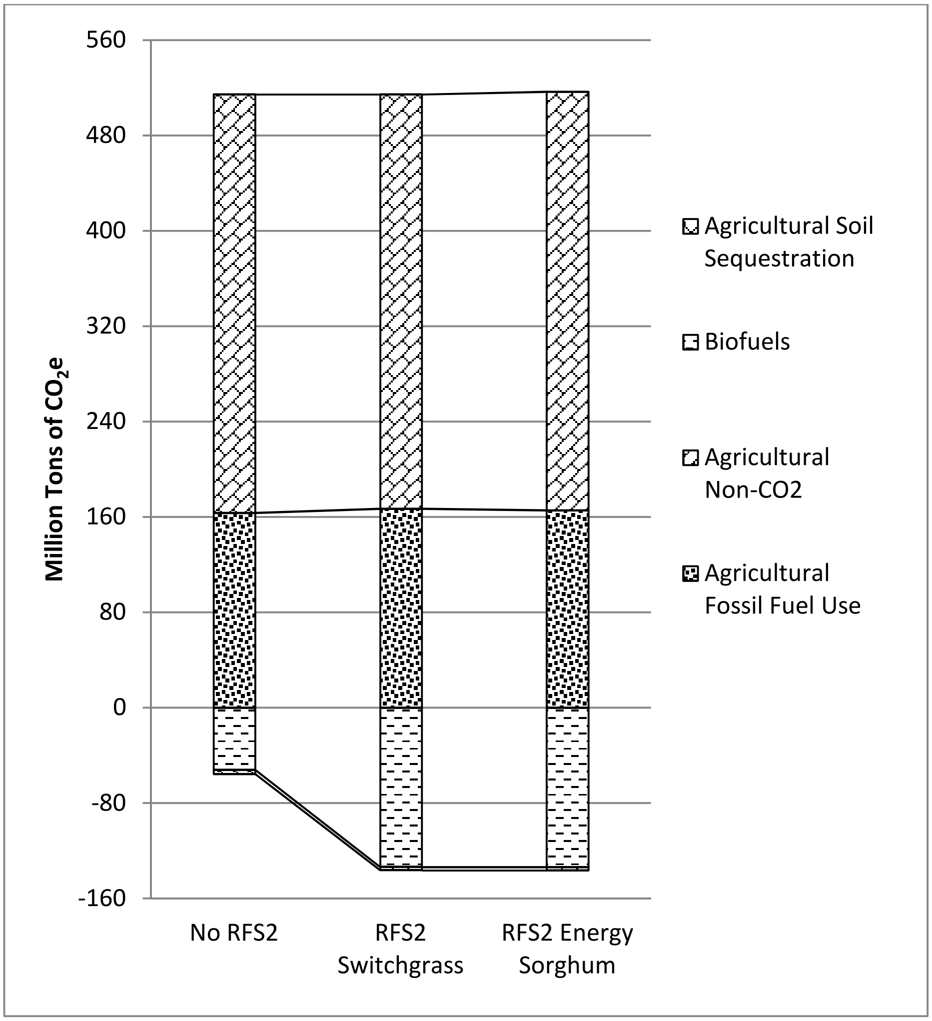


Figure II-4 GHG mitigation potential by sources under alternative scenarios, 2030.

Figure II-4 presents a decomposition of annual GHG mitigation potential by sources under alternative scenarios. Not surprisingly, agricultural fossil fuel use-related GHG emissions increase under RFS2 due to increased crop production activity, as indicated by expanded overall cropland acreage shown in Figure II-2. The inclusion of energy sorghum slightly reduces fossil fuel use-related GHG emissions.

For the non-CO_2 category, the net effects of RFS2 are insignificant. Possible reasons may include that the N_2O emissions reduction via decreasing cropland pasture is offset by increases in N_2O emissions associated with increased crop production activity. Moreover, the energy sorghum presence has minimal net influence on non-CO_2 GHG emissions. Recall that the GHG mitigation via reducing demand for cropland under the RFS2 Energy Sorghum scenario may be offset by increases in N_2O emissions caused by more extensive use of fertilizer in energy sorghum production.

The biofuels-related GHG emission reduction appears to be greater under the RFS2 scenarios as expected. Note that this category just counts GHG offsets attributed to fossil fuel replacement.

For agricultural soil-related GHG mitigation, the RFS2 Energy Sorghum scenario exhibits slightly greater GHG mitigation potential than the RFS2 Switchgrass scenario. The less intense conversion of cropland pasture to cropland (till the opposite) under the RFS2 Energy Sorghum scenario, as presented in Figure II-3, may have contributed to this enhanced, albeit small, soil-based GHG mitigation.

Sensitivity Analysis on Energy Sorghum Yield Growth Rate

A sensitivity analysis is carried out to examine the effects of alternative yield growth rates of energy sorghum on fuel ethanol production and agricultural commodity price and production, as yield is a principal factor for the competitiveness of an energy crop (Jain et al. 2010).

Table II–10 Energy Sorghum Yield Growth Rate Sensitivity Scenarios.

Sensitivity Scenario	*Annual Yield Growth Rate*	*Yield Index 2030 (Base=100)*
low (default)	0.09%	102.29
mid	0.70%	119.05
high	1.30%	138.11

As Table II-10 shows, a range of annual yield growth rates for energy sorghum is used for the sensitivity analysis. The 0.09% yield growth rate is the default rate for sorghum production in FASOMGHG. And this “default” scenario is identical to the RFS2 Energy Sorghum scenario presented in the main results. The 0.7% yield growth rate is the estimated least-squares exponential parameter fitting the trend line of sorghum yields over the period of 1960 – 2009, while the 1.3% yield growth rate is the estimated least-squares exponential parameter fitting the trend line over the period 1950 – 2009. The historical data on grain sorghum yields are from the USDA NASS.

Table II-11 presents the feedstock-specific ethanol production in 2030 under alternative sensitivity scenarios. As the yield growth rate gets higher, the usage of energy sorghum for cellulosic ethanol production also gets larger, though the increments are small because energy sorghum is estimated to already play a dominating role under the default scenario. Nonetheless, the high yield growth rate does not lead to a greater total amount of cellulosic ethanol above the RFS2 mandated volume, implying that the cellulosic RFS2 mandates are upper limits.

Table II–11 Ethanol Production in Million Gallons per Year by Feedstock under Alternative Sensitivity Scenarios, 2030.

	mid		*high*	
	level	change from *low*	*level*	change from *low*
Cellulosic Ethanol				
Energy Sorghum	13,026	2	13,041	18
Bagasse	661	-2	645	-18
Grain Ethanol				
Corn	14,985	0	14,985	0
Barley	30	0	30	0
Total	28,701	0	28,701	0

Table II–12 Fisher Indices Relative to the No RFS2 Baseline (Base=100) under Alternative Sensitivity Scenarios, 2030.

	mid		*high*	
	level	change from *low*	level	change from *low*
All Crops				
Price	102.4	-0.5	102.2	-0.7
Production	100.7	0.2	101.0	0.5
Export	96.7	0.6	97.1	1.0
Livestock				
Price	100.1	-0.1	100.1	-0.2
Production	100.2	0.2	100.3	0.3

Table II-12 compares the agricultural price and production indices across the sensitivity scenarios. As we see, higher yield growth rates of energy sorghum results in decreases in crop and livestock price indices, alleviating greater price pressure compared to the default scenario. Correspondingly, crop export indices are greater under the higher yield growth rate scenarios, suggesting a strengthened restoration of the No RFS2 export level. Besides, the inclusion of energy sorghum with higher yield growth rates implies a further reduced energy crop demand for cropland and thereby further restored grain and feed crop production, as suggested by the increases in production indices. In addition, the high yield growth rate may imply a decreased need for corn expansion to substitute for displaced grain sorghum.

Conclusions and Discussion

The research presented in this essay modifies and extends of the work of Beach and McCarl (2010) using FASOMGHG to examine the impacts of introducing high-yielding energy sorghum as energy feedstock, reporting on changes in projections of feedstock mix of biofuels production, agriculture market equilibrium, land use, and GHG mitigation potential. Instead of modeling both the agricultural and forestry sectors as conducted in Beach and McCarl (2010), the research presented in this essay focuses on the U.S. agricultural sector due to time constraints. Nonetheless, the U.S. agriculture-based biofuels production under RFS2 as featured in EPA (2010) lends support to the legitimacy of focusing on the agricultural sector for this study.

In general, this research finds that the presence of energy sorghum under RFS2 significantly alters the feedstock mix of biofuels production, compared to the projection in Beach and McCarl (2010). Energy sorghum is found to have the potential to play a dominating role in providing cellulosic ethanol to fulfill RFS2 requirements.

The introduction of energy sorghum under RFS2 has market implications also. Price pressure on conventional crops is found to be alleviated, except for grain sorghum, as opposed to the RFS2 scenario in which lower-yielding switchgrass takes the lead. The estimated concentration of energy sorghum production in the Great Plains and the Southwest regions suggests a direct cropland use competition between grain and energy sorghum that contributes to the grain sorghum exception. Nonetheless, overall price pressure is reduced.

Regarding cropland usage, the inclusion of high-yielding energy sorghum under RFS2 is estimated to release more cropland for conventional crops production than under the RFS2 Switchgrass scenario. Meanwhile, markedly less cropland is utilized for energy crops production.

For land use change, both the RFS2 Switchgrass and Energy Sorghum scenarios show maximum amount of CRP land reversion allowed. Also, the RFS2 Switchgrass scenario shows cropland pasture conversion to cropland as opposed to the No RFS2 baseline. The presence of energy sorghum, on the contrary, is projected to release cropland for cropland pasture use, though smaller in magnitude than under the No RFS2 scenario, implying an ameliorated land use competition.

The cropland usage and land use change summarized above have implications for agricultural GHG performance also. According to Searchinger et al. (2008), N_2O emissions may increase as a result of increased utilization of existing cropland – against the background of large-scale, agriculturally-sourced biofuels production. The research presented in this essay generally agrees with this statement, however, it also suggests that the increase in N_2O-sourced GHG emissions may be offset by decreases in livestock-related GHG emissions – as implied by reduced land conversion to cropland pasture under RFS2.

Compared to the RFS2 Switchgrass scenario, the introduction of energy sorghum reduces overall cropland usage – thereby plausibly reducing N_2O emissions; meanwhile it stimulates cropland conversion to cropland pasture – thus potentially increasing livestock-related GHG emissions. Moreover, recall that energy sorghum production requires more fertilizer inputs than switchgrass. The net effects of the energy sorghum presence on non-CO_2 emissions are thus projected to be minimal.

This work also conducted a sensitivity analysis examining the effects of assumed high yield growth rates of energy sorghum, since the yield per acre is a critical factor for the competitiveness of biofuel feedstock given the biofuels production and processing specification in FASOMGHG. Selected results show that as the yield growth rate goes higher, the role of energy sorghum is further enlarged for cellulosic ethanol production. Moreover, higher energy sorghum yield growth rates bring about further price alleviation, production increases plus restoration of export levels for agricultural commodities, as measured by Fisher indices.

To repeat, high-yielding energy sorghum can take a lead role in producing ethanol to meet cellulosic RFS2 mandates. And in general reduced land use competition and price pressure, as well as restoration of production and export levels of agricultural commodities would follow except for grain sorghum. Besides, the net effects of including energy sorghum on agricultural GHG mitigation potential are insignificant.

These results suggest that the advantage of introducing high-yielding energy crops under RFS2 largely lies in relaxing land use competition and ameliorating distorted market equilibriums; the agricultural GHG performance does not necessarily improve however.

At least two caveats need to be noted for this study however. Firstly, only the agricultural component of FASOMGHG is employed for the RFS2 effects examination. A comparison of Beach and McCarl (2010) and the research presented in this essay suggests that by allowing a potential excess land supply from the forestry sector, agriculture may have more cropland and may utilize more crop residues for cellulosic ethanol production. The projections of price increases and production decreases under RFS2 in this work are thus likely overestimated.

Secondly, this study does not consider other potential high-yielding energy crops such as miscanthus and energy cane. By including a more diversified portfolio of high-yielding energy crops, the issue of regional concentration of dedicated energy crops production may be alleviated – thereupon distortions in market equilibriums can be ameliorated. Future research that incorporates an expanded set of biofuel feedstocks – either regionally restricted or nationally applicable – is desirable to develop a more comprehensive understanding of the implications of using dedicated second generation biofuel feedstocks for RFS2 purposes.

CHAPTER III

U.S. AGRICULTURE UNDER CLIMATE CHANGE: AN EXAMINATION OF CLIMATE CHANGE EFFECTS ON EASE OF ACHIEVING RFS2

Key to agricultural production, climate and the atmosphere provide essential inputs such as solar radiation, water, and CO_2 for plant and animal growth (Antle 2009). Changes in climate and the atmosphere, projected by IPCC WGI (2007) as inevitable for the coming decades, raise concerns regarding the adaptive ability and/or the likely responses of the agricultural sector. The challenges and opportunities facing today's agriculture within the climate change context are however at least two-fold: in addition to adapting to a potentially more variable climate, agriculture may also take on the additional role of mitigating GHG emissions – such as providing renewable fuels to replace fossil fuels to some extent (Smith and Olesen 2010). In the U.S., a large-scale GHG mitigation effort through biofuels production, pursuant to the Renewable Fuel Standard (RFS2), is already unfolding. A question thus arises naturally for the RFS2-relevant U.S. agricultural sector: will climate change make it harder to meet the volume goals set in the RFS2 mandates, considering that both climate change and RFS2 may have significant impacts on U.S. agriculture?

Current climate change studies have shown a growing interest in "synergies" between the agriculture-based mitigation and adaptation under climate change and/or identification of an optimal mix of the two – which implicitly acknowledges the existence of some trade-off between the two (IPCC WGII 2007; Klein, Schipper and

Dessai 2005; Rosenzweig and Tubiello 2007; Smith and Olesen 2010). In other words, the issue of integrating agricultural mitigation and adaptation under climate change is increasingly mentioned and discussed, although few studies have examined if such "synergies" or the opposite exists, and if they exist, to what extent.

Readjusting the framework of "mitigation versus/in conjunction with adaptation under climate change" outlined in the studies above, the research presented in this essay aims to examine the "synergy", or perhaps the opposite, between mitigation and climate change effects (with adaptation) that are taking place or will very likely occur within the U.S. agricultural sector, focusing on the implementation of RFS2 – a principally U.S. agriculture-based GHG mitigation activity – and the autonomous, evolving farm-level adaptation under climate change. This study will report on the "synergy" (or the opposite) outcomes of U.S. agricultural welfare, agricultural market equilibrium, land use change, and the RFS2 biofuel production mix with respect to a baseline in which climate change and RFS2 are absent.

The remainder of this essay is organized as follows. In the literature review part, a visit of climate change studies focusing on agriculture and a discussion of several major research approaches are presented. Then in the methodology part, this essay introduces how climate change effects and adaption activities have been incorporated in FASOMGHG to date and how the investigation of climate change interacting with RFS2 for this study is carried out. After that, this essay displays and discusses model results. Finally, this essay concludes and discusses about future research.

Literature Review

Numerous studies have been carried out to gain an understanding about climate change impacts on agricultural production since the publication of the first IPCC report in 1990 (Antle 2009). For example, crop response simulation models that combine agronomic response of plants and management practices were developed to estimate the physical, biological, and economic outcomes in agricultural system (Schimmelpfennig et al. 1996). Frequently used crop modeling systems include CERES, CENTURY, SOYGRO and PNNL EPIC models (Izaurralde, Brown and Rosenberg 1999; Izaurralde et al. 2003; Reilly et al. 2003; Tubiello et al. 2002). These simulation models can estimate changes in both crop yields and demand for irrigation water under transient climate scenarios (Reilly et al. 2003) and they are predominant tools for estimating likely climate effects on crop yields (Schlenker and Roberts 2008). An apparent strength of the simulation models is that they can incorporate the whole distribution of weather conditions over the growing season to develop a distribution of yield and water use outcomes. However, they typically take production systems and nutrient applications as exogenous (Schlenker and Roberts 2008), limiting the involvement of autonomous adaptation.

Another approach to study the effects of climate on crop production involves statistical estimation using cross-section data (the spatial analogue approach). This spatial analogue method attempts to forecast how cool regions would adopt warm regions’ practices if climate gets warmer by comparing production activities in warm and cool regions under past and current climate (Schimmelpfennig et al. 1996). Unlike crop simulation models, the spatial analogue approach is considered to have a greater success in capturing farmers' behavioral and adaptive responses (Schlenker and Roberts 2008) and possibly some other macro factors. Nevertheless, this approach is subject to the problem of omitted variables – its likely inadequate specification of underlying physiological processes can lead to biased estimates. Moreover, the inherent assumptions of exogenous prices and policy regimes plus a lack of treatment of CO_2 effects on crop yields may seriously limit the predictive power of this method.

In addition to crop simulation models and the spatial analogue method reviewed above, integrated assessments spanning several disciplines are carried out to explore possible outcomes of agricultural production under climate change also. The integrated assessments typically use estimates from the aforementioned crop simulation models and econometric studies as data inputs. According to Antle (2009), the most comprehensive study to date is the U.S. Global Climate Research Program's national agricultural assessment – namely, Reilly et al. (2003). This assessment used the ASM model – the agricultural component in FAOMSGHG – to simulate the U.S. agricultural sector under transient climate scenarios, taking into consideration climate impacts on crops, pesticide use, irrigation water supply and demand, livestock grazing supply and international trade effects. In addition, this study carried out case studies examining climate change effects on nutrient loading to the Chesapeake Bay and groundwater depletion of the Edwards Aquifer in Texas, offering forecasts of environmental consequences under climate change. These case studies imply research opportunities that pay attention to multiobjectives, such as meeting environmental standards and adapting agriculture to climate change simultaneously.

Earlier major integrated assessments include the works of Adams et al. (1990) and Adams et al. (1995). In their research, General Circulation Models (GCM) for future climate projections, models of plant science, hydrology and agricultural economics are utilized. Their results suggest that irrigated cropland acreage will expand and regional patterns of U.S. agriculture will shift under future climate change.

Collectively, the typical procedure of integrated assessments introduced above is as follows: firstly, obtain biophysical estimates describing changes in crop yields, irrigation water requirements and resources availability under GCM projections of interest; then incorporate these data and their associated economic terms into economic models to generate solutions from which people can draw implications of climate change and/or evaluate economic returns to possession of or improvement in adaptation ability in agriculture.

The literature review so far has focused on agricultural climate change effects and (autonomous) adaptation to projected future climate change. Examples of real successful adaptations in U.S. history include agricultural production in irrigated areas in the Texas High Plains and the dryland areas in the Midwestern Corn Belt (Rose and McCarl 2008). Besides adapting to climate forces, producers also adapt to or respond to changes in economic and policy conditions. An examination of historic shifts in crop production locations conducted in Reilly et al. (2003) suggests that non-climate forces – government policies that help limit farmers’ financial losses – have likely dominated the climate forces in inducing the northward and the westward crop movements in the U.S., when there is evidence showing that climate has changed over the past 100 years. As for today, the U.S. agricultural sector has actively responded to biofuel policy incentives and/or mandates in facilitating the expansion of biofuels production since the early 2000s which otherwise may not occur, as the works of McCarl and Schneider (2001) and Schneider and McCarl (2003) point out that without a relatively high carbon price (incentive) biofuels production in the U.S. has no role in GHG emissions reduction among many other agriculture-based mitigation strategies. Note that so far, the climate change studies that used FASOM did not include the information of U.S. biofuels production since 2000, not to mention the RFS2 mandates.

In a well-functioning market system that rewards successful decisions and penalizes less wise decisions, a continuous and appropriate adaption to changes in environmental conditions (here including economic and policy conditions also) is a natural result (Reilly 1999), as demonstrated in some of the examples above. For agriculture under climate change, this continuity in adaptation could lead to quite different outcomes from the “do nothing” counterfactuals derived under transient climate scenarios. As pointed out in Rose and McCarl (2008), adaptation is nothing new but an ongoing routine in the agricultural sector. Meanwhile, Rose and McCarl (2008) also noted the inertia in the socioeconomic system that can slow down taking actions to change. In FASOMGHG, each region’s crop mix under new market equilibriums is constrained to fall within the convex space built by the mixes observed in the past 20 years, and for climate change scenarios, a possible 200 mile northward migration of crop mixes is allowed (Adams et al. 2005). The research presented in this essay considers these crop mix constraints a reasonable approach to capture both the inertia and evolving adaptation mentioned above.

Methodology

The agricultural component of FASOMGHG that models the land use allocation within the conterminous, “lower 48 states” U.S. agricultural sector (the U.S. agricultural sector henceforth for brevity) is employed to investigate the effects of autonomous adaptation-adjusted climate change (adaptation-adjusted climate change henceforth) coupled with RFS2 on U.S. agriculture for this study. To obtain a general picture about the implications of adaptation-adjusted climate change and RFS2 in the land use context, a simplified graphic analysis following Mendelsohn and Dinar (2009) is provided in Figure III-1, where D_{crop} and D_{pature} denote the two major competing uses – cropland demand and cropland pasture demand – for the U.S. cropland base, respectively, with p being the equilibrium cropland price.

As we see, on the right side of the figure, RFS2 is expected to induce a greater demand for cropland – D^{r}_{crop}, to the right of D_{crop}, resulting in an increase in cropland base allocation to cropland ($q^{r} > q$) and a decrease in allocation to cropland pasture. A higher cropland price ($p^{r} > p$) is also expected. On the left side of the figure, we show the situation in which adaptation-adjusted climate change causes a lower national cropland demand D^{c}_{crop} and a lower cropland pasture demand $D^{c}_{pasture}$, resulting in a decrease in allocation of cropland base to cropland ($q^c < q$) and a lower cropland price ($p^c < p$).

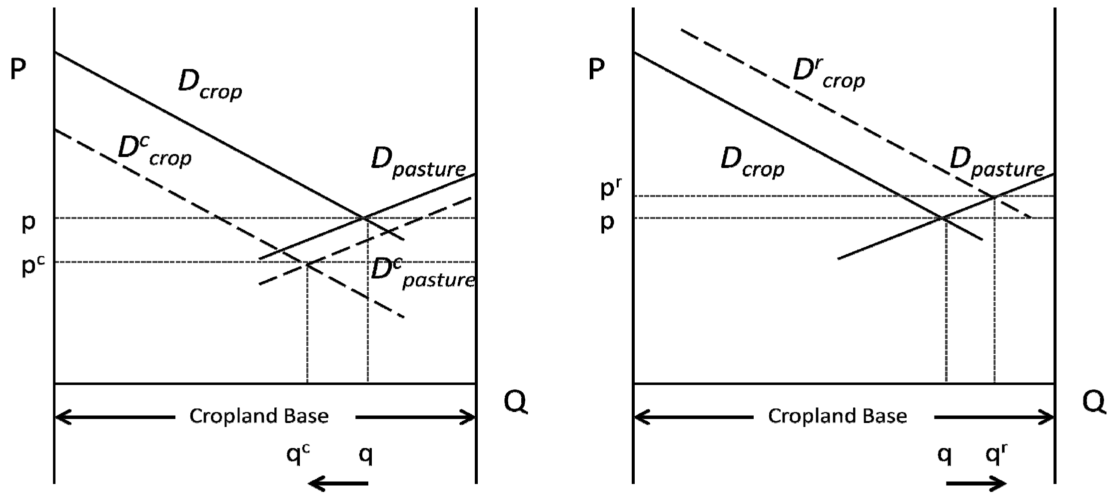


Figure III-1 Impacts of adaptation-adjusted climate change (left) and RFS2 (right) on cropland use allocation.

Note that the adaptation-adjusted climate change impacts on national cropland usage are indefinite, since the varying regional effects can lead to either a higher or a lower overall demand for cropland. Consider, crop production may respond to climate change by shifting to relatively more productive regions under a competitive market system. If the effect of higher productivity outweighs the effect of cropland reallocation, then a reduced cropland demand would result; vice versa. Similarly, if the effect of higher forage productivity is greater than the pasture reallocation effect, then a less pressing pasture demand would follow; vice versa. The equilibrium land use allocation will depend on the relative shifts of cropland and pasture demand curves. In addition, though Figure III-1 shows a scenario in which adaptation-adjusted climate change and RFS2 impose opposite effects on cropland use allocation, it does not necessarily suggest that adaptation-adjusted climate change and RFS2 would counteract each other on changing agricultural welfare, as market-mediated outcomes involve price effects also.

FASOMGHG Overview

To outline the conceptual framework of FASOMGHG, an abstract mathematical depiction of the FASOMGHG structure is presented below.

$$(3.1)\quad \max \quad \sum_t \{[\sum_h \int_0^{Z_{ht}} P_{dht}(Z_{ht})dZ_{ht} - \sum_i \int_0^{X_{it}} P_{sit}(X_{it})dX_{it}](\frac{1}{1+r})^t\}$$

$$(3.2)\quad s.t. \quad Z_{ht} - \sum_\beta \sum_k c_{h\beta kt} Q_{\beta kt} \le 0, \quad \forall h,t$$

$$(3.3)\quad - X_{it} + \sum_\beta \sum_k a_{i\beta kt} Q_{\beta kt} \le 0, \quad \forall i,t$$

$$(3.4)\quad \sum_k b_{j\beta kt} Q_{\beta kt} \le Y_{j\beta t}, \forall j,\beta,t$$

$$(3.5)\quad Z_{ht}, \quad X_{it}, \quad Q_{\beta kt} \ge 0, \quad \forall i,h,\beta,k,t$$

where

$P_d(Z)$ is the inverse demand function for commodities traded on market, and $P_s(X)$ the inverse supply function for purchased inputs;

Z presents the quantities of commodities, with h being the index;

Q refers to the levels of production processes, including primary (e.g. corn) and secondary (e.g. biofuels) commodities production and processing, with β indexing firm and *k* indexing process;

X presents the amounts of purchased inputs, with *i* being the index;

Y refers to the resources endowments such as land supply, with *j* as its index.

Also, *t* indexes year and *r* is the discount rate.

Turning to the mathematical structure, equation (3.1) sets the objective of maximizing the net present value of aggregate consumer and producer surpluses over time; equation (3.2) describes the relationship between final produced commodities and production processes, with coefficient *c* giving the output yield Z_h for production process *Q*; equation (3.3) connects production processes and input factors, with coefficient $a_{i\beta k}$ describing the input usage level X_i for production process *Q*; equation (3.4) links production processes with resources endowments, with $b_{j\beta k}$ representing the production process-specific resource usage; finally equation (3.5) points out that the quantities or levels of commodities, purchased inputs, and production processes need to be non-negative.

Incorporating Climate Change Effects

In the literature review section, the strengths of integrated assessments are discussed and the importance of including continuous, evolving adaptation is noted. To match the RFS2 schedule, the research presented in this essay sets the time scope focusing on the period of 2000 – 2035 and uses the Hadley and Canadian GCM projections for 2030 as the climate change background. The incorporation of climate change effects in previous climate change studies using FASOM, the predecessor of FASOMGHG, such as Reilly et al. (2003) has typically involved modification of coefficients. This research also follows the same procedure and uses the same data to include the changes, as detailed below:

(a) The crop and livestock yields – coefficient *c* in equation (3.2) – are adjusted to reflect the climate change effects. Data on crop yield changes with variety and planting date adaptation arise from CERES, SOYGRO, and CENTURY models, as detailed in Reilly et al. (2003), Tubiello et al. (2000) and Tubiello et al. (2002). Data on changes in livestock-related products production are drawn from Adams et al. (1999).

(b) Coefficient (*a*) parameters in equation (3.3) are modified to reflect climate change induced changes in input usages. Specifically, the data on pesticide use changes with respect to the Hadley and Canadian climate change projections are obtained from Chen and McCarl (2001). And the data on changes in cropping use of irrigation water are from the same source as crop yield changes specified in step (a).

(c) The right-hand-side (RHS) values in equation (3.4) are altered to reflect the climate change effects on resources availability. As documented in Reilly et al. (2003), the data on changes in irrigation water supply are from Gleick and Adams (2000), and the grazing supply data are modified by utilizing the crop models mentioned in step (a).

(d) International trade effects that consider the changes in agriculture elsewhere in the world are incorporated in the demand and supply functions in equation (3.1). The average of GISS and UKMO estimates from Reilly et al. (2001) are used, following McCarl (2006).

Phasing in Biofuels Production

As noted in the literature review section, so far the climate change studies using FASOMGHG have not included the expansion of U.S. biofuels production since the early 2000s yet. To reflect this biofuel growth and the RFS2 policy, further constraints are imposed in the model as below.

(3.6) $$Z_{h^*t} \geq M_{h^*t}, \forall h^*, t$$

(3.7) $$Z_{h^*t} \leq M_{h^*t}, \forall h^*, t$$

where h^* indicates grain-based ethanol and cellulosic ethanol, and M represents the projected or mandated volumes.

Scenarios Used

Table III-1 presents the scenarios used for this study. Each scenario represents a particular combination of biofuels production assumption – with or without RFS2 – and adaptation-adjusted climate change effects, which include the information of estimates for agricultural production performance, resources availability, and etc. under the Hadley or Canadian climate change scenario.

Table III–1 Scenarios for the Climate Change and RFS2 Study.

Scenario	*RFS2*	*Climate Change*		
		None	Hadley (with adaptation)	Canadian (with adaptation)
Base		√		
BaseHC			√	
BaseCC				√
RFS2	√	√		
RFS2HC	√		√	
RFS2CC	√			√

Note that the future climate change projections, based on which the agricultural adaptation-adjusted climate change effects were derived, are assumed to be independent of the RFS2 mitigation efforts in this study due to data limitation.

Data

As summarized in Reilly et al. (2001), the Hadley and the Canadian scenarios employed in this study are in the middle and the high end of the 1996 IPCC projections of climate change by the year 2100, respectively. Specifically, the Hadley scenario predicts a 1.4 °C increase in temperature and a 6% increase in precipitation by 2030, whereas the Canadian scenario projects an average 2.1 °C temperature increase and a 4% precipitation decline.

In this study, most adaptation-adjusted climate change effects data for the Hadley and Canadian climate scenarios are adapted from Reilly et al. (2003). The data sources are mentioned in the FASOMGHG modification part above. To conserve space, here the data on changes in corn and switchgrass yields under the projected climate change scenarios are presented to demonstrate the estimated differentiated yield outcomes of conventional crops versus dedicated energy crops. The adaptation-adjusted climate change effects on hay production derived from the CENTURY model (Reilly et al. 2003) are applied to switchgrass.

Table III–2 Projected Adaptation-Adjusted Climate Change Effects on Switchgrass vs. Corn Yields in Percentage Changes, 2030.

Region	*Hadley*			*Canadian*		
	switchgrass	corn		switchgrass	corn	
		dry	irrig.		dry	irrig.
Corn Belt	3.98	10.14	-3.25	-15.57	8.84	-7.78
Great Plains	3.59	19.20	-3.18	-5.64	18.10	-6.20
Lake States	2.01	50.92	40.45	-3.95	55.20	47.37
Northeast	1.34	5.16	-3.80	-11.40	-0.41	-8.70
Pacific Northwest East	27.54	17.60	-2.50	10.46	19.20	-7.30
Pacific Southwest	30.96	17.60	-2.50	46.86	19.20	-7.30
Rocky Mountains	8.21	25.55	-4.00	9.86	21.95	-8.80
South Central	-16.72	7.60	-1.23	-44.25	-2.61	-14.56
Southeast	-17.70	3.60	2.10	-41.50	-8.20	-15.80
Southwest	-11.31	11.60	-3.60	-19.09	3.60	-14.50

Data source: U.S. National Assessment (Reilly et al. 2003)

Table III-2 presents the region-specific percentage change estimates for corn and switchgrass yields under the Hadley and Canadian climate scenarios in 2030. Broadly speaking, the estimates of adaptation-adjusted climate change effects on dryland corn are more positive or less negative than those of switchgrass. Adaptation-adjusted climate change effects on irrigated corn are however negative except in the Lake States and Southeast regions. Meanwhile, the Canadian climate scenario appears to have greater diminishing effects on crop yields than the Hadley scenario.

As for the specification of biofuels production assumptions, the No RFS2 and RFS2 representations have followed Beach and McCarl (2010). Specifically, under RFS2, the amount of agriculturally-sourced cellulosic ethanol is set to be at least 13.7 BGY by 2022, and the amount of grain-based ethanol is limited to be no more than 15 BGY. In the absence of RFS2, the cellulosic ethanol production level is set to be 0.25 BGY by 2022, and no more than 13.6 BGY of grain ethanol can be produced.

Model Results

Welfare, Price and Production

Table III-3 presents the predicted U.S. agricultural welfare changes relative to the baseline (no climate change, no RFS2) in 2030 under alternative scenarios. As we see, without RFS2, the Hadley climate induces a noticeably greater reduction in producer income and a larger increase in consumer surplus than the Canadian climate. With RFS2, however, both the consumer surplus and the producer income increase under climate change, though the increments in consumer surplus are slightly smaller than under the No RFS2 scenarios. Notice that in the absence of climate change, the RFS2 program reduces consumer surplus and markedly increases producer income. The comparison of the No RFS2 versus RFS2 climate change scenarios thus suggests that the RFS2 presence plays a supporting role in maintaining/enhancing the welfare accrued to agricultural producers under climate change, whereas the adaptation-adjusted climate change substantially ameliorates the negative effects of RFS2 on consumer surplus supporting the welfare accrued to consumers.

Table III–3 U.S. Agriculture Welfare Changes Relative to Base in $2004 Billion Dollars under Alternative Scenarios, 2030.

	No RFS2		*RFS2*		
	Hadley	Canadian	None	Hadley	Canadian
Consumer Surplus	12.95	9.41	-3.12	12.36	8.24
Producer Surplus	-1.61	-0.86	9.48	3.20	4.18

A look into the price and production indices under alternative scenarios may help understand the changes in predicted welfare. As Table III-4 shows, significantly elevated crop production occurs under climate change scenarios, with the Hadley projection bringing about greater increase than the Canadian projection. The Hadley price indices are correspondingly lower than the Canadian ones. With the RFS2 presence, increases in price indices and decreases in production indices would result, implying an increased tension between supply and demand in conventional crop markets under RFS2 and moreover, an counteracting effect of RFS2 against adaptation-adjusted climate change on conventional crop production.

For the livestock sector, both the Hadley and the Canadian climate scenarios bring about increased livestock production, possibly due to increased supply of feed. Price indices for livestock decrease accordingly. Compared to the changes in crop production and price, the changes in livestock production and price are much smaller in magnitude. In addition, the RFS2 impacts appear to be small.

Table III–4 Fisher Indices Changes Relative to Base (Base=100) under Alternative Scenarios, 2030.

		Conventional Crops		*Livestock*	
		Price	Quantity	Price	Quantity
No RFS2	Hadley	83.5	119.9	96.0	104.0
	Canadian	86.3	116.0	97.6	103.2
RFS2	None	105.6	98.6	101.0	98.6
	Hadley	85.2	119.6	96.3	103.9
	Canadian	88.6	115.6	98.0	103.2

The noticeably higher (crop) price indices and slightly lower production indices under RFS2 correspond to the welfare-enhancing/maintaining effects of RFS2 on producer income shown in Table III-3. Meanwhile, the markedly lower price indices and higher production indices for both crop and livestock under the climate change scenarios explain the beneficial impacts of adaptation-adjusted climate change on consumer surplus.

Land Use

Figure III-2 displays the cropland acreage and usage between energy crops – principally switchgrass, the designated energy crop following Beach and McCarl (2010) – and conventional grain and feed crops.

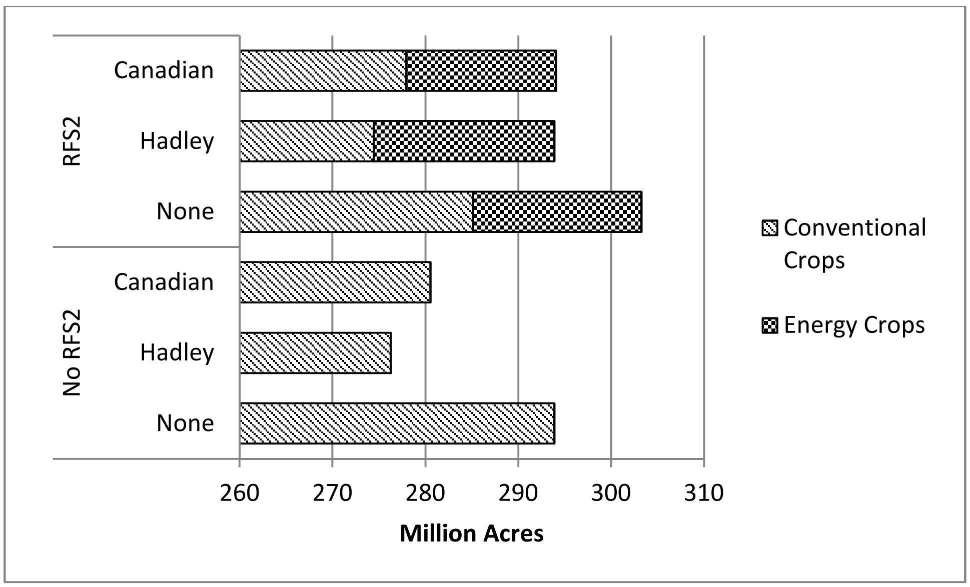


Figure III-2 Cropland acreage and usage under alternative scenarios, 2030.

As shown in the figure, significantly less cropland is devoted to conventional crops production under climate change scenarios, especially the Hadley ones. Also, visibly less cropland is allocated to switchgrass production under the Canadian climate scenario, compared to the Hadley one. This reduced farming of energy crops for RFS2 purposes may reflect the overall yield-enhancing effects of the Canadian climate on switchgrass production and/or decreased reliance on switchgrass for cellulosic ethanol production. Meanwhile, compared to the Hadley climate scenarios, the cropland acreage of conventional crops under the Canadian climate scenarios is larger, indicating the generally smaller yield-enhancing effects of the Canadian climate on crops production.

Note that the RFS2 presence also reduces the cropland allocation to conventional crops. However, this may be largely driven by the competition between energy crops versus conventional crops farming rather than the generally yield-enhancing effects of adaptation-adjusted climate change.

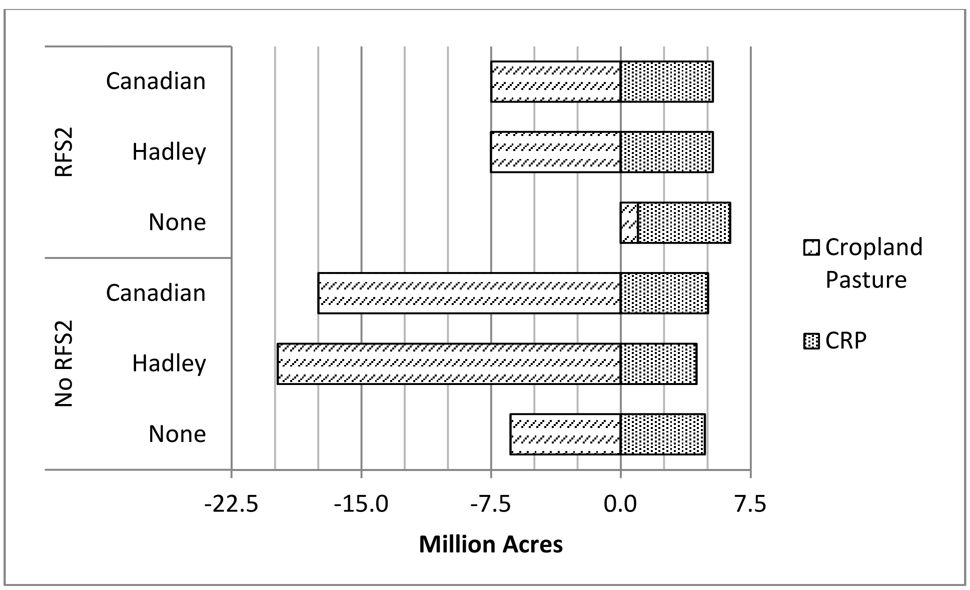


Figure III-3 Land use change under alternative scenarios, 2030.

Figure III-3 portrays the net accumulative exchanges between cropland, cropland pasture and CRP land by 2030 under alternative scenarios. The climate change scenarios exhibit considerably greater cropland conversion to cropland pasture, with the Hadley climate inducing more so than the Canadian climate. On the other hand, the RFS2 program reduces the cropland conversion, substantially – in the absence of climate change, it is shown to even result in net cropland pasture conversion to cropland. As for CRP land, climate change has minimal effects on its reversion to cropland, whereas RFS2 induces maximum allowable CRP land reversion regardless of the presence of adaptation-adjusted climate change.

Overall, the aggregate effects of climate change and RFS2 on cropland usage (shown in Figure III-2) and land use exchange (shown in Figure III-3) are fairly small compared to the base scenario (no climate change, no RFS2). Despite that, the welfare changes brought by adaptation-adjusted climate change and RFS2 are significant – both consumer surplus and producer income increase as shown in Table III-3, with climate change favoring consumer welfare and RFS2 supporting producer welfare. The comparison of land use under the base scenario and the RFS2 climate change scenarios also suggests that under climate change, with adaptation included, the almost same amount of cropland can accommodate both providing grain and feed crops for human and livestock consumption and producing RFS2-relevant energy crops.

Accompanying the land use changes illustrated in Figures III-2 and III-3 are also changes in cropland prices across the scenarios, as presented in Table III-5.

Table III–5 Cropland Price under Alternative Scenarios, 2030.

	No RFS2			*RFS2*		
	None	Hadley	Canadian	None	Hadley	Canadian
Value ($ /acre)	94.46	80.80	85.52	121.78	90.36	97.53

As the table shows, climate change scenarios exhibit lower cropland prices than the "none" climate change scenarios, corresponding to the reduced cropland usage (a lower cropland demand) shown in Figure III-2. This climate change-induced decrease in cropland price is even more pronounced under RFS2. The lower cropland price also helps explain the increment in cropland conversion for pasture use shown in Figure III-3, as the land opportunity cost decreases. Moreover, the RFS2 program raises cropland price, as the demand for cropland increases.

Fuel Ethanol Production

Table III-6 provides a comparison of feedstock-specific fuel ethanol production across the scenarios. It appears that in the absence of climate change, switchgrass – as a dedicated energy crop – provides the majority of cellulosic ethanol under RFS2. With climate change, however, a greater amount of crop residues and other kinds of dedicated energy crops are used for cellulosic ethanol production, partially replacing switchgrass-based ethanol. In particular, under the RFS2 Canadian scenario, corn residue delivers significantly more ethanol than under other scenarios. In brief, the presence of climate change reduces the biofuel delivery potential of switchgrass, and diversifies the biofuel feedstock portfolio with a focus on conventional crop residues.

Table III–6 Feedstock-Specific Ethanol Production in Million Gallons per Year under Alternative Scenarios, 2030.

	No RFS2			*RFS2*		
	None	Hadley	Canadian	None	Hadley	Canadian
Cellulosic Ethanol						
Dedicated Energy Crops						
Switchgrass	-	-	-	12,744	12,804	9,011
Hybrid Poplar	-	-	-	-	58	218
Willow	-	-	-	61	55	57
Crop Residues						
Corn Residue	-	-	-	20	6	3,648
Wheat Residue	-	-	-	15	91	31
Sorghum Residue	-	-	-	-	7	18
Rice Residue	-	-	-	6	1	-
Processing Residues						
Bagasse	250	250	250	735	558	598
Sweet Sorghum Pulp	-	-	-	106	106	106
Grain Ethanol						
Corn	13,544	13,544	13,544	14,985	14,985	14,985
Barley	23	-	1	-	-	-
Oats	-	23	22	-	-	-
Sweet Sorghum	-	-	-	30	30	30
Total	13,818	13,818	13,818	28,701	28,701	28,701

Sensitivity Analysis on Energy Crops Mix

A sensitivity analysis on energy crops mix is conducted to examine the potential changes in model outcomes, since the presence of an expanded set of energy crops may alter the RFS2 implications for U.S. agriculture (McCarl and Zhang 2011) and thus the potential counteracting effects of RFS2 against adaptation-adjusted climate change on U.S. agriculture.

Table III–7 RFS2 Scenarios for Sensitivity Analysis on Energy Crops Mix.

Scenario	*RFS2 Mandate*		*Climate Change*		
	Switchgrass	Energy Sorghum	None	Hadley	Canadian
RFS2-ES	√	√	√		
RFS2HC-ES	√	√		√	
RFS2CC-ES	√	√			√

The high-yielding energy crop energy sorghum investigated in Chapter II in this dissertation is added into the energy crops mix for the analysis. The sensitivity scenarios employed are shown in Table III-7 above. Each scenario includes both switchgrass and energy sorghum as dedicated energy crops and assumes the presence of RFS2 mandates with or without climate change.

Data for Sensitivity Analysis

As introduced in Chapter II, energy sorghum crop budgets were constructed based on Texas AgriLife Extension experiment data, and in general, the energy sorghum yields are more than twice the yields of switchgrass.

Table III–8 Proxy Climate Change Effects on Energy Sorghum Yields in Percentage Changes, 2030.

	Hadley		*Canadian*	
	dryland	irrigated	dryland	irrigated
Corn Belt	117.31		87.84	
Great Plains	56.22	24.59	71.19	31.33
Northeast	33.32		27.54	
Pacific Southwest	107.46	39.03	52.88	45.06
Rocky Mountains	107.46	28.10	52.88	49.49
South Central	33.70	11.95	28.42	9.69
Southeast	31.98		25.34	
Southwest	34.85	18.30	52.00	17.09

Data source: U.S. National Assessment (Reilly et al. 2003)

The estimates of adaptation-adjusted climate change effects on grain sorghum production are used as proxy for climate change effects on energy sorghum. Table III-8 presents the estimated adaptation-adjusted climate change effects on energy sorghum yields, for both dryland and irrigated conditions if applicable, in different regions. The effects appear to be uniformly positive and fairly large under both the Hadley and Canadian climate change scenarios.

Sensitivity Analysis Results

Table III-9 presents the estimated U.S. agricultural welfare changes relative to the “no climate change, no RFS2” base scenario. Again, we find that without climate change, producer income increases whereas consumer surplus decreases.

Table III–9 U.S. Agriculture Welfare Changes Relative to Base in $2004 Billion Dollars under Alternative RFS2 Sensitivity Scenarios, 2030.

	RFS2 Energy Sorghum					
	None	change from RFS2	Hadley	change from RFS2HC	Canadian	change from RFS2CC
Consumer Surplus	-1.27	1.86	12.68	0.32	9.36	1.12
Producer Surplus	4.32	-5.16	0.22	-2.98	0.56	-3.61

Table III–10 Crop and Livestock Fisher Indices Relative to Base (Base=100) under Alternative RFS2 Sensitivity Scenarios, 2030.

	RFS2 Energy Sorghum					
	None	change from RFS2	Hadley	change from RFS2HC	Canadian	change from RFS2CC
Crops						
Price	102.90	-2.74	84.51	-0.66	87.16	-1.41
Quantity	100.47	1.83	120.41	0.83	116.58	0.93
Livestock						
Price	100.29	-0.75	96.10	-0.17	97.64	-0.32
Quantity	99.95	1.30	104.04	0.12	103.25	0.05

With climate change, however, the increases in producer income get smaller, with the Hadley climate having greater negative effects. Consumer surplus, on the other hand, sees significant increases, with the Hadley climate having larger positive effects. In general, the changes in energy crops mix do not change the direction of welfare changes relative to the baseline. Nonetheless, the magnitudes of the changes associated with the energy sorghum mix are fairly smaller, compared to the counterpart switchgrass only scenarios (as in the main results). In other words, the introduction of high-yielding energy sorghum considerably dilutes the RFS2 impacts on U.S. agricultural welfare – to the extent that the effects of adaptation-adjusted climate change dominate.

Table III-10 presents the 2030 price and production indices for both crop and livestock under alternative sensitivity scenarios. As similar to the findings in Table III-4, the inclusion of climate change expands crop production, and in turn results in lower price indices. The climate change effects are less significant on livestock indices. The energy sorghum mix does not bring about significant changes (albeit noticeable) in the indices compared to the counterpart switchgrass only scenarios.

Table III-11 summarizes the fuel ethanol production under alternative sensitivity scenarios by feedstock. As we see, the introduction of climate change enlarges the role of energy sorghum in providing cellulosic ethanol, eliminating switchgrass-based and many other kinds of cellulose-based ethanol. This result suggests that under climate change, heat-tolerant (as indicated by the assumed positive climate change effects shown in Table III-8), high-yielding dedicated energy crop such as energy sorghum could gain an extra advantage in providing RFS2 biofuel feedstocks.

Table III–11 Feedstock-Specific Ethanol Production under Alternative RFS2 Sensitivity Scenarios, 2030.

	RFS2 Energy Sorghum					
	None	change from RFS2	Hadley	change from RFS2HC	Canadian	change from RFS2CC
Cellulosic Ethanol						
Dedicated Energy Crops						
Switchgrass	-	-12,744	-	-12,804	-	-9,011
Hybrid Poplar	-	0	-	-58	-	-218
Willow	-	-61	-	-55	-	-57
Energy Sorghum	13,023	13,023	13,103	13,103	13,116	13,116
Crop Residues						
Corn Residue	-	-20	-	-6	-	-3,648
Wheat Residue	-	-15	-	-91	-	-31
Sorghum Residue	-	0	-	-7	-	-18
Rice Residue	-	-6	-	-1	-	0
Processing Residues						
Bagasse	663	-72	583	26	570	-28
Sweet Sorghum Pulp	-	-106	-	-106	-	-106
Grain Ethanol						
Corn	14,985	0	14,985	0	14,985	0
Barley	30	30	-	0	28	28
Oats	-	0	30	30	2	2
Sweet Sorghum	-	-30	-	-30	-	-30
Total	28,701	0	28,701	0	28,701	0

Conclusions and Discussion

The “synergy”, or perhaps the opposite, between mitigation and climate change effects on agriculture are explored. The research presented in this essay focuses on the U.S. agricultural sector under projected climate change, incorporating both RFS2 – a large-scale agriculture-based activity with some GHG mitigation characteristics – and climate change effects (with autonomous adaptation) on agriculture, into FASOMGHG to investigate the aggregate effects of the two on U.S. agriculture. Meanwhile, the analysis compares the climate change scenarios with and without RFS2, to gain an insight into if RFS2 adds to or counteracts the effects of climate change, as well as how climate change affects RFS2.

In terms of climate change incorporation, this study largely follows the methods used in the Reilly et al. (2001) and McCarl (2006). For biofuels it follows the work of Beach and McCarl (2010) to include biofuels production and processing and RFS2 scenarios.

The aggregate effects of RFS2 and climate change are projected to be positive for both consumer welfare and producer income. While offsetting each other, the beneficial impacts of climate change dominate the negative effects of RFS2 on consumer welfare, and the supporting effects of RFS2 outweigh the decreasing effects of climate change on producer income – a “synergy” in terms of welfare effects between mitigation and climate change is thus suggested.

A closer examination of agricultural price and production indices further shows that climate change, with adaptation considered, can induce increases in crop and livestock production, suppressing price levels to the extent that producer income decreases. RFS2, on the other hand, raises prices and diminishes production, resulting in greater producer surplus and noticeable losses in consumer welfare.

Regarding cropland usage, under climate change, markedly less cropland is estimated to be devoted to crop production. RFS2, in contrast, induces greater use of cropland for crop production, counteracting the climate change effects on cropland usage. Moreover, a comparison of land use change between the scenarios suggests that under climate change, with adaptation included, the U.S. agricultural sector can accommodate both conventional crops production and the farming of RFS2 energy crops without disrupting the general land use allocation. Thereby the controversy over indirect land use change caused by RFS2 may be alleviated.

In brief, the RFS2 impact and the climate change impact on U.S. agriculture act in opposite directions, as demonstrated in the aspects of agricultural welfare, agricultural commodity price and production, and land use. Nonetheless, a "synergy" measured by agricultural welfare changes is indicated.

As for RFS2 biofuels production, the model results suggest that climate change alters the feedstock mix by inducing greater use of crop residues and non-switchgrass energy crops for cellulosic ethanol production. A sensitivity analysis on including high-yielding energy sorghum under climate change further suggests that climate change would enlarge the role of heat-tolerant energy crops such as energy sorghum in fulfilling

RFS2 mandates. In addition, with high-yielding energy sorghum, the RFS2 effects on U.S. agricultural welfare would become much less pronounced, to the extent that the climate change effects dominate.

The research presented in this essay is subject to several limitations, however. First, the data on climate change effects on crop production performance are obtained from crop simulation models mentioned in the literature review section, and thus this research is subject to the limitations of those crop models.

Second, the Hadley and the Canadian climate projections employed in this study were derived based on the IPCC's IS92A emissions scenario (Reilly et al. 2003). According to IPCC (2000), this IS92A GHG emissions scenario is often referred to as the "business-as-usual" scenario, thereupon climate change mitigation efforts such as RFS2 are not well-reflected in this scenario. This may imply that the estimates of climate change effects employed by this study are overestimated ones – against the backdrop of RFS2 among many other GHG mitigation activities.

Given above, future research may have to utilize more-developed estimates of climate change effects on agriculture, and consider the climate feedbacks of mitigation activities. Further, an examination of regional effects would be desirable, given that the distributional effects of climate change, in conjunction with RFS2, on agriculture may be more relevant to agricultural producers.

CHAPTER IV

HOW CLIMATE FACTORS INFLUENCE THE SPATIAL DISTRIBUTION OF TEXAS CATTLE BREEDS[2]

Genetic traits in beef cattle are of great importance because they biologically determine reproductive characteristics, carcass quality and range of mature weights of beef cattle – key factors that define economic returns to the beef sector producers (Greiner 2009; Hammack 2010d). In particular, for cow-calf operations, breed has a significant impact on efficiency and profitability because the varying genetic traits alter fertility rates and reproductive performance of cows, as well as physical performance of calves (Hammack 2010c).

Reproductive and physical performance is also influenced by environmental factors, in particular climate and forage conditions (Hammack 2010a). Some breeds are more adapted to hot and humid environment – such as *Bos indicus* originated from India (Hammack 2010d), while in history some breeds are not. For example, some purebred Europe-originated *Bos taurus* breeds have proved to be not suited to the harsh climate in South Texas (Paschal 2011). Nonetheless, compared to *Bos indicus*, *Bos taurus* breeds typically yield better quality beef (Turner 1980), and market rewards a premium to certain *Bos taurus* carcasses (Hammack 2010b; Meyer 2010).

[2]This essay expands on Y.W. Zhang, A. Hagerman, and B.A. McCarl, “How Climate Factors Influenced the Spatial Allocation of and Returns to Texas Cattle Breeds” (paper presented at the 2011 AAEA & NAREA Joint Annual Meeting, Pittsburgh, Pennsylvania, July 24 – 26, 2011), available at http://purl.umn.edu/103826.

Given that breed performance differs, beef cattle producers have an incentive to select the breed that delivers the profit maximizing combination of market-desired and production-suitable traits (Hawkes, Lillywhite and Simonsen 2008). The result of such choices can be observed – for example, the use of heat tolerant crossbred cattle with *Bos indicus* inheritance is popular in hotter South Texas (Paschal 2011), whereas the use of the less heat tolerant breed Angus (a kind of *Bos taurus* breed) and Angus-crosses are common in Virginia (Greiner 2009). As described in Winder, Rankin and Bailey (1992), producers have to figure out whether "the increase in animal productivity stemming from the use of *Bos indicus* breeds outweigh the [price] discounts seen from the resulting calves Southwest cow-calf producers sell".

Cow-calf operators typically raise cows and calves on open space rangelands, indicating direct exposure to climatic conditions. Animal science research suggests that high temperatures and humidity have detrimental effects on reproductive performance of cows and growth of calves, as summarized in St-Pierre, Cobanov and Schnitkey (2003). Also, rising temperature and decreasing precipitation can negatively influence forage availability and quality (Craine et al. 2010), making it more challenging for cattle to graze appropriately. Thereupon, in regions where climate change brings hotter conditions, beef sector producers may have to take adaptive measures. For Texas, the climate change projections largely fall in the hotter and drier range (U.S. Global Change Research Program 2009) and thus abatement of heat stress effects on livestock production may be an issue. In fact, under current climate heat stress is estimated to have already resulted in an annual economic loss of $370 million for the U.S. beef industry

(St-Pierre, Cobanov and Schnitkey 2003) and Texas is among the major beef production regions.

Though the abatement of heat stress effects on livestock production may take many forms, the research presented in this essay focuses on adaptation through selection of cattle breed – as have been done by U.S. cattlemen as they deal with different climates across the country (Paschal 2011). Cow-calf operators are thus expected to exhibit breeds that are more adapted to hotter environments as we observe their choices across the landscape southward. And we will thereupon observe the balance breeds as they vary across the semiarid Southwest region.

An understanding of how climate factors play in cattle breed selection across the landscape may reveal adaptation strategies that can help cow-calf producers and other stakeholders make better informed decisions to deal with potential future climate change. Texas is chosen for the research presented in this essay, given its diverse climatic and ecological conditions across the territory, and the aforementioned challenge of heat stress abatement.

The remainder of this essay is organized as follows. First a review of livestock-centered or closely related climate change studies is given. Then the multivariate probit model to be employed is introduced. After that, the data are presented, and the estimation results are displayed and discussed. Finally, conclusions, limitations and future research are presented.

Literature Review

Cross-sectional analysis, spatial analogue studies have been widely carried out in climate change studies focusing on the agricultural sector (Schimmelpfennig et al. 1996). The underlying assumption behind the spatial analogue method is that on the margin relatively colder areas will follow and adopt practices in relatively warmer areas as climate warms. Cross-section observations of certain practices or outcomes are viewed as results of natural experiments and the cross-section data differentials may serve as the source of identification for effects of climate variation.

Seo et al. (2009) conducted a cross-section study of climate effects on livestock management in Africa. They predict that climate change would cause small farms to move toward raising livestock species and away from planting crops. They also predict a shift among livestock species away from temperate animal species to heat-tolerant species. Seo, McCarl and Mendelsohn (2010) also carried out a South America-based livestock adaptation study, finding that climate is a significant determinant in livestock species adoption. They also find that under projected climate change, the probability of adopting beef and dairy cattle decreases while the probability of selecting sheep increases.

In the U.S. livestock sector, Adams et al. (1999) examined potential climate change impacts on U.S. crop and livestock sectors and find mild climate change impacts on livestock. Mu and McCarl (2011) find that climate change induces a land use shift from cropland to pasture as well as a decrease in cattle stocking rate.

The literature reviewed above indicates that climate factors can have significant influence on livestock performance and play a noteworthy role in land allocation, adoption of livestock species, and spatial pattern of livestock production. However, no “within species”, breed-specific examinations have been carried out in these studies.

Regarding methodology, some of the aforementioned literature employs the multinomial choice model using cross-section data to forecast likely adjustments in livestock species adoption under climate change. The multinomial choice model may not be appropriate for our breed selection study however, considering that breed candidates facing livestock producers are not necessarily mutually exclusive – which can be particularly true if the spatial unit is large enough to cover multiple breeds.

In brief, so far few studies have explored the breed-specific issue quantitatively. The research presented in this essay thus aims to investigate how spatially differentiated climate conditions have influenced beef cattle breed selection, by analyzing cross-sectional binary choices of *Bos taurus*, composite, and *Bos indicus* breeds in Texas. The data on breed association membership provide the information on observable binary choices of cattle breeds.

Model Development

Following Zilberman et al. (2004), we present a simplified conceptual graphic analysis of cattle breed selection in Texas in Figure IV-1. As will be detailed later, across Texas, from inland north to coastal south, the incidence of *Bos indicus* breed association membership would become greater as *Bos indicus* is heat-tolerant.

In Figure IV-1, we assume that each kind of breed has a range of geographic locations where it thrives, and the distributions of value potentials associated with raising cattle breeds are unimodal. Note that each location represents a particular set of climatic, ecological, and market conditions to which cow-calf producers may respond. And if climate gets warmer, the value potentials are assumed to shift to the right, indicating an "inland, northern" migration of cattle breeds – in particular *Bos taurus*. Note that the direction of "coastal south to inland north" depicted in Figure IV-1 is just one dimension related to geographic location among many other dimensions.

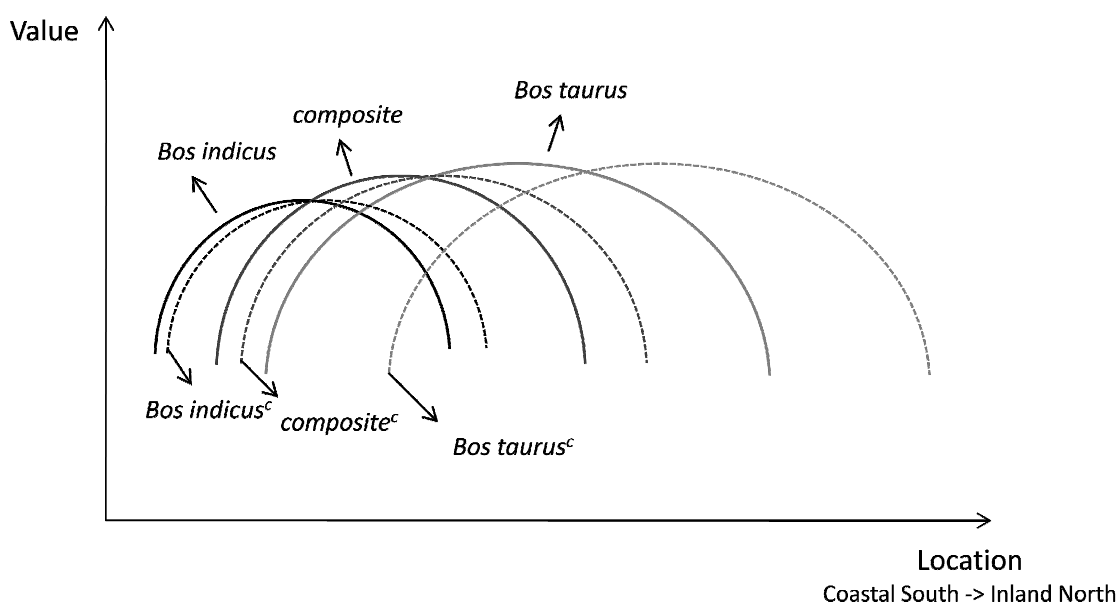


Figure IV-1 Value potentials of raising *Bos taurus*, composite, and *Bos indicus* breeds across the Texas landscape under current climate and a warmer climate.

Multivariate Probit Model

A three-equation multivariate probit model is employed to examine the binary choices of cattle breeds across the Texas landscape. The multivariate probit model is selected largely due to the data limitation problem and the characteristics of the binary choice data we can obtain. As will be detailed later, the dependant variables are the county-level binary choices of the three major types of cattle breeds introduced earlier. The three major types of cattle breeds are not mutually exclusive choice elements before the decision unit – some counties may have all the three types, while some counties may select only one of them. Thus the traditional multinomial model is not applicable here because it typically requires a single pick from multiple choice elements, whereas the multivariate probit model can allow multiple picks from multiple choice elements.

Following Greene (2003), the latent process for the multivariate probit model is as follows.

(4.1) $$y^*_{i,j} = X'_{i,j}\beta_j + \varepsilon_{i,j}$$

(4.2) $$y_{i,j} = \begin{cases} 1, & if\ y^*_{i,j} > 0 \\ 0, & otherwise \end{cases}$$

where *i* denotes the observation unit – county, and *j* = 1, 2, 3, representing *Bos taurus*, composite, and *Bos indicus*, respectively. Also, *y** is an unobserved variable that indicates the difference between benefit and cost associated with selecting a breed or not selecting a breed under given county-level conditions, and *y* is the observed outcome – select or not select a breed. And, *X* is the vector of explanatory variables that represent county-level conditions. In addition, the error terms ε follow a trivariate normal distribution presented in equation (4.3).

$$\text{(4.3)} \qquad \begin{pmatrix} \varepsilon_{i,1} \\ \varepsilon_{i,2} \\ \varepsilon_{i,3} \end{pmatrix} \sim N\left[\begin{pmatrix} 0 \\ 0 \\ 0 \end{pmatrix}, \begin{pmatrix} 1 & \rho_{12} & \rho_{13} \\ \rho_{21} & 1 & \rho_{23} \\ \rho_{31} & \rho_{32} & 1 \end{pmatrix}\right] = N[0, R]$$

where $\rho_{jk} = \rho_{kj}$, with both j and k referring to cattle breed.

Note that the "*Bos taurus*, composite, and *Bos indicus*" arrangement aims to represent a typical, reasonably complete spectrum of breed candidates faced by Texas breeders.

The user-written STATA program, *mvprobit*, developed by Cappellari and Jenkins (2003) is employed by this study. A brief overview of the likelihood function development for the multivariate probit model is given below, following the mathematical derivations in Cappellari and Jenkins (2003) and Greene (2003).

Specifically, we firstly have

$$\text{(4.4)} \qquad Q_i = \begin{bmatrix} 2y_{i,1} - 1 & & \\ & 2y_{i,2} - 1 & \\ & & 2y_{i,3} - 1 \end{bmatrix}$$

and

$$\text{(4.5)} \qquad b_i = \left(X'_{i,1}\beta_1, X'_{i,2}\beta_2, X'_{i,3}\beta_3\right)'$$

Q in equation (4.4) is a matrix differentiating the 1 versus 0 choices, and it is applied to the latent process shown below.

(4.6) $$\mu_i = Q_i b_i$$

(4.7) $$\Sigma_i = Q_i R Q_i$$

Collecting the information above, the log likelihood function is then given by

(4.8) $$L = \sum_{i=1}^{n} \ln \Phi(\mu_i ; \Sigma_i)$$

Data

The membership data from cattle breed-specific associations are used to generate the binary choice data for the dependant variables. As argued earlier, breed-specific breeder membership is the observable breed choice. The most recent 2010 membership data from the Texas Angus Association, the Texas Hereford Association, the Texas Brangus Breeders Association, the United Braford Breeders, the Texas Brahman Association and some other continental breed associations are collected.

Note that Angus and Hereford belong to *Bos taurus*, Brahman belongs to *Bos indicus*, and Brangus and Braford are composite breeds having *Bos taurus* and *Bos indicus* traits. These breeds are selected because they are among the most popular ones in Texas (Hammack 2010d; Paschal 2011). The county-level “adoption” of one breed in this study means that there is at least one breeder of that particular breed residing in the given county. We assign 1 to adoption and 0 for the otherwise situation.

Table IV–1 Variable Definitions.

Variable	*Unit*	*Description*
Climate Conditions		
thisum	1	the average of July and August temperature-heat index, derived from maximum temperature and dew point temperature in July and August
tminwin	°C	the average of December and January minimum temperature
Forage Conditions		
prepspr	mm	the average of March and April precipitation
prepsum	mm	the average of July and August precipitation
range	1000 acres	the acreage of rangeland
pasture	1000 acres	the acreage of pasture land
hay	dry ton/acre	hay yield per acre of land
topo	1	topography code indicating topographic variation, where 1 indicates flat regions (the lower bound) and 21 indicates high mountains (the upper bound)
Market Conditions		
angusbsp	$100/head	Angus bull price derived from sale transactions in spring
angusfmsp	$100/head	Angus female price derived from sale transactions in spring
hfbsp	$100/head	Hereford bull price derived from sale transactions in spring
hffmsp	$100/head	Hereford female price derived from sale transactions in spring
taurusbsp	$100/head	the lot-size weighted average of Angus and Hereford bull prices in spring
taurusfmsp	$100/head	the lot-size weighted average of Angus and Hereford female prices in spring
brangusbsp	$100/head	Brangus bull price derived from sale transactions in spring
brangusfmsp	$100/head	Brangus female price derived from sale transactions in spring
County Characteristics		
cattle	1000 heads	cattle inventory
income	$1000	median household income

Following Hammack (2010a), the decision-making of breed selection primarily involves consideration of production and market conditions. Production conditions include two major groups of factors – climate and forage. Market conditions refer to the economic returns and costs.

Explanatory variables in this study thus include extreme climate conditions that impose critical physiological effects on cattle, such as the frequently mentioned summer heat stress measured by temperature-humidity index (THI) (Hoffmann 2010; Mader, Johnson and Gaughan 2010), spring precipitation that is important for annual forage growth, grazing availability that influence forage conditions, market prices for difference breeds, and county characteristics such as cattle inventory and household income levels. The detailed information on variables used in this study is presented in Table IV-1.

Summary Statistics and Data Sources

Table IV-2 displays the numbers of counties for each type of breed membership pattern. Recall that the outcome of breed selection from a choice set does not have to be a single pick at county level. As we see, about half of the Texas counties – the (1, 0, 0) group – exhibit *Bos taurus* membership only. And the next largest group (1, 1, 0) consists of the counties having both *Bos taurus* and composite membership. The third largest group (1, 1, 1) shows an all-included choice. *Bos taurus* breed thus appears to be the most popular in Texas.

Based upon the cattle inventory data which will be detailed later, the (0, 0, 0) group shown in Table IV-2 possesses 5.53% of total Texas cattle inventory. Thus the breed selection data derived from breeder membership data are reasonably complete for the Texas analysis.

Table IV–2 Breed Selection Pattern of Texas Counties, 2010.

Bos taurus	*Composite*	*Bos indicus*	*Count*
1	1	1	29
1	1	0	62
1	0	1	12
1	0	0	120
0	1	1	0
0	1	0	6
0	0	1	2
0	0	0	23
Total			254

Table IV-3 provides the summary statistics of the variables included in the econometric specification. The climate data are obtained by processing the gridded data from the PRISM Climate Group, Oregon State University. The monthly averages of maximum temperature, minimum temperature, dew point temperature and precipitation over the period of 1980-2009 for the 254 Texas counties are utilized. The summer temperature-heat indices are calculated based upon formulas provided in Lawrence (2005) and Mader, Johnson and Gaughan (2010) by using maximum temperature and dew point temperature. Following the argument in Mendelsohn, Nordhaus and Shaw (1994) and Schlenker, Hanemann and Fisher (2006), the long-term climate values – instead of the short-term weather data typically featured by intense variation – are employed for this study, since our interests are in understanding how breeders have incorporated the lasting climate effects into their decision making.

Table IV–3 Summary Statistics.

Variable		*Mean*	*Std. Dev.*	*Min*	*Max*
Climate	thisum	82.09	1.98	72.98	85.98
	tminwin	1.35	3.71	-6.62	10.18
Forage	prepspr	57.54	26.75	7	115.01
	prepsum	60.87	16.26	38.71	134.585
	range	364.68	385.46	0	2668.46
	pasture	43.34	57.80	0	359.39
	hay	2.62	0.61	1.06	5.85
	topo	5.39	3.95	1	19
Market	angusbsp	22.67	1.28	17.52	27.34
	angusfmsp	26.91	4.73	11.51	79.31
	hfbsp	31.33	4.97	10.69	65
	hffmsp	26.83	3.91	7.3	47.22
	taurusbsp	25.95	1.76	18.83	37.99
	taurusfmsp	26.88	3.42	17.24	60.08
	brangusbsp	29.81	2.05	20.41	40.75
	brangusfmsp	27.16	2.66	7.3	47.22
County	cattle	52.66	64.30	2	550
	income	40.24	9.34	21.35	80.06

Note: See Table IV-1 for variable definitions.

To obtain the county-level climate data mentioned above, spatial information is needed. The longitude and latitude data for Texas counties are thus obtained from the TravelMath.com, which returns coordinate information for each county query. These geo-data are then used to extract the point climate data from the PRISM Climate Group data files for Texas counties. The geo-data are also used to calculate the Euclidean distances between counties, by using the formula $d_{a,b} = \sqrt{(lat_a - lat_b)^2 + (lon_a - lon_b)^2}$, where *lat* refers to latitude and *lon* represents longitude, with *a* and *b* denoting two different counties. The distance data are further utilized to help generate the county-specific market prices for cattle breeds, which will be introduced later.

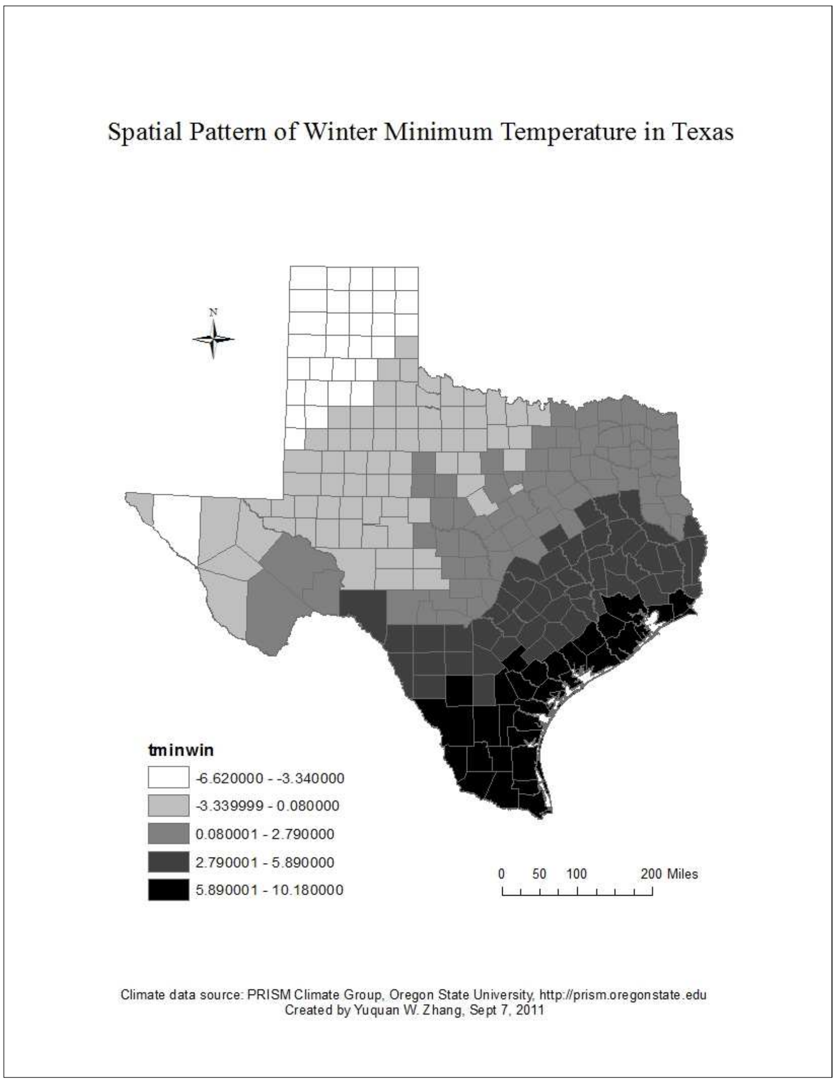
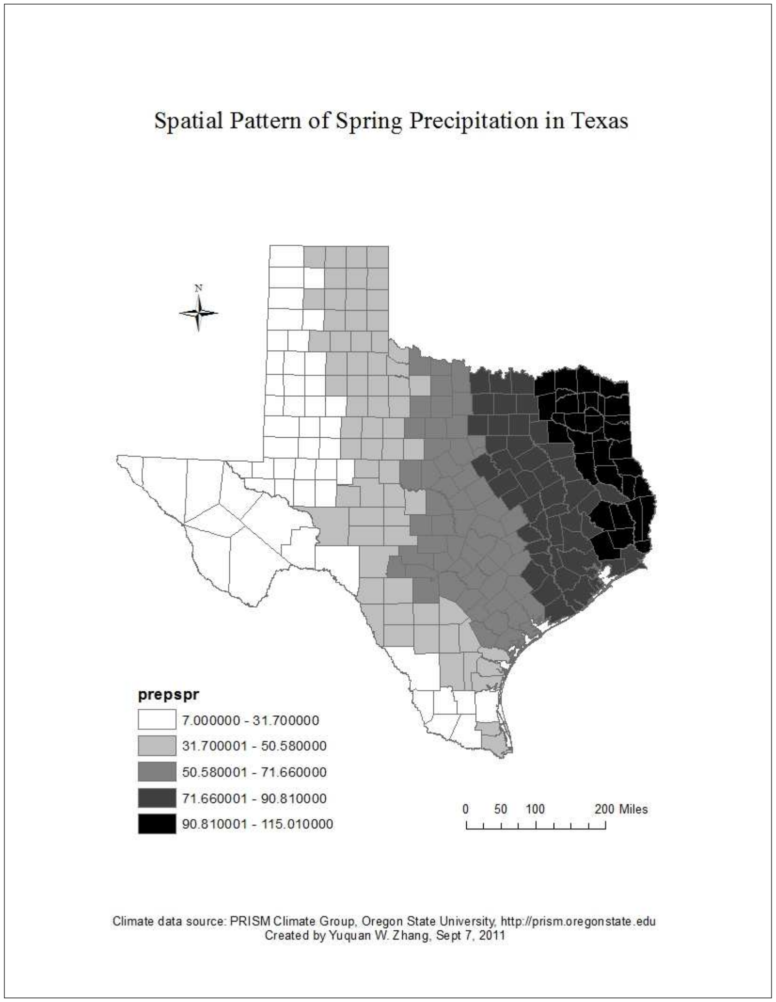


Figure IV-2 Spatial pattern of winter minimum temperature in Texas.



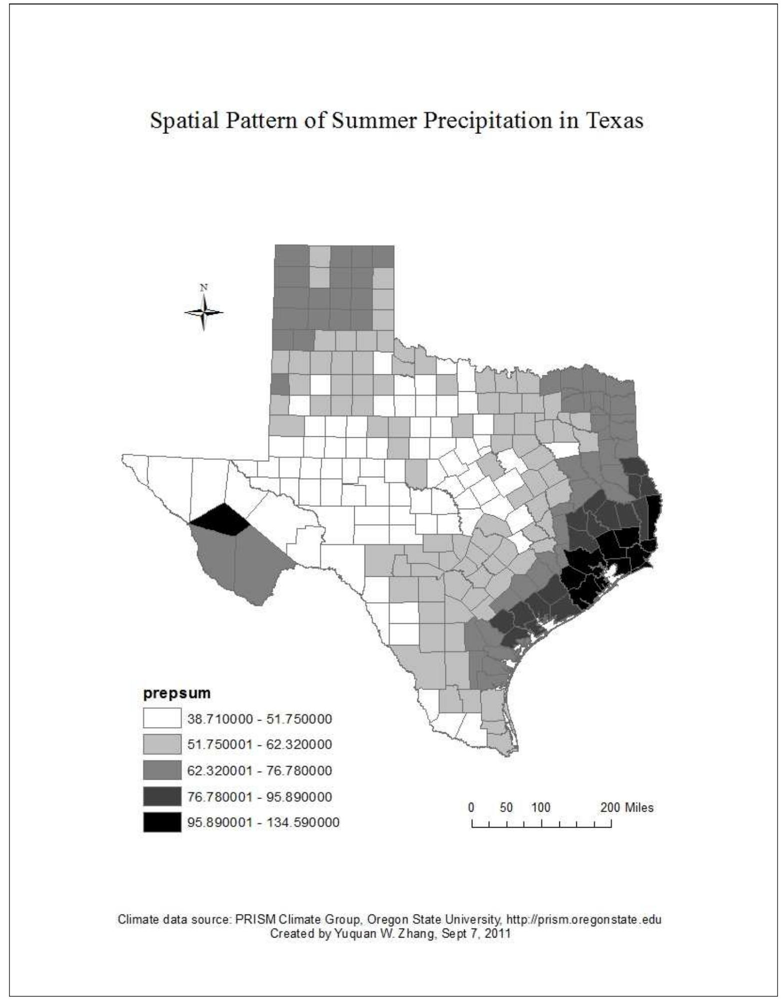


Figure IV-3 Spatial patterns of spring (left) and summer (right) precipitations in Texas.

Figure IV-2 presents the 30-year average winter minimum temperatures across the Texas landscape. As we see, the temperature gradient is coastal-inland oriented, with warmer temperatures locating on the coastal side. The summer temperature-heat index map will be shown later. Spatial patterns of spring and summer precipitations are also presented. The left side of Figure IV-3 shows that spring precipitation increases in an eastward direction, whereas the right side of the figure suggests a coastal concentration of summer precipitation.

Data on forage conditions including acreages of managed pastureland and native rangeland, spring and summer precipitation, hay productivity, and topography code were assembled. The grazing land data were drawn from the Trend Visualizer provided by the Texas A&M Institute of Renewable Natural Resources (IRNR), using 2007 data. The precipitation data are obtained from the PRISM Climate group as introduced earlier. Hay yields are derived based upon the county-level hay acres and quantities data from the 2007 Census of Agriculture, USDA National Agricultural Statistics Service (NASS). Topography code data are from the Natural Amenities Scale program, USDA Economic Research Service.

The price data were drawn from the year 2009 sale reports from the online databases of the American Angus Association and the American Hereford Association, plus the Brangus Journal published by the International Brangus Breeders Association. To obtain consistent and comparable market prices for breeds, the spring prices are selected to exclude seasonal variation effects. The spring prices are selected for use also because the Brangus data for Texas in 2009 are only available for spring. Moreover, to take into account regional variation such as transportation costs and information access, we assume that each county assigns greater weight to prices from nearer market locations than from further market locations. Specifically, for a county facing prices from multiple market locations, the "effective" price for that county is given by the formula $p_i = \sum_m \{[(1/d_{m,i}) / \sum_m (1/d_{m,i})] p_m]\}$, where p_i is the price for county i, p_m the price in a market location county (m), and $d_{m,i}$ the Euclidean distance between county i and market location m, as introduced earlier. Thereupon county-specific averages of prices from multiple market locations weighted by the multiplicative inverses of distances to market locations are generated for each county. Furthermore, the lot size data in the sale reports are used to weight the derived Angus and Hereford prices in developing the average *Bos taurus* prices.

As for county characteristics, the 2010 cattle inventory data are collected from the USDA NASS. And the most recent 2007 county-level median household income data are obtained from the Small Area Income and Poverty Estimates, the U.S. Census Bureau.

Spatial Allocation of Cattle Breeders

To gain a rough idea about the effects of summer climates on breed selection, displays of the spatial allocation of *Bos taurus*, composite, and *Bos indicus* breeders across the Texas landscape – against the 30-year average summer heat stress background – are provided.

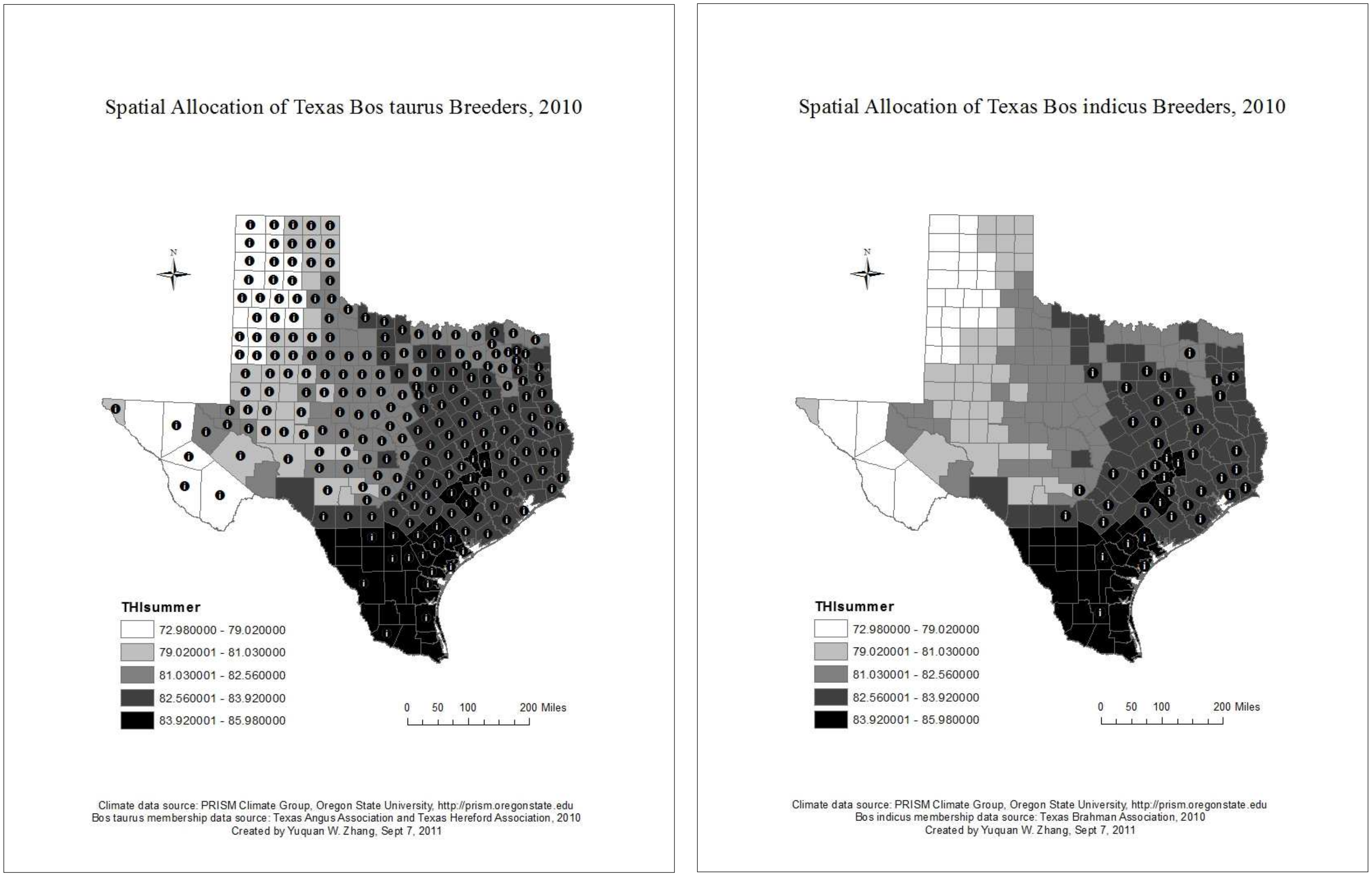


Figure IV-4 Spatial allocation of *Bos taurus* (left) vs. *Bos indicus* (right) breeders against the background of summer heat stress (THIsummer) in Texas, 2010.

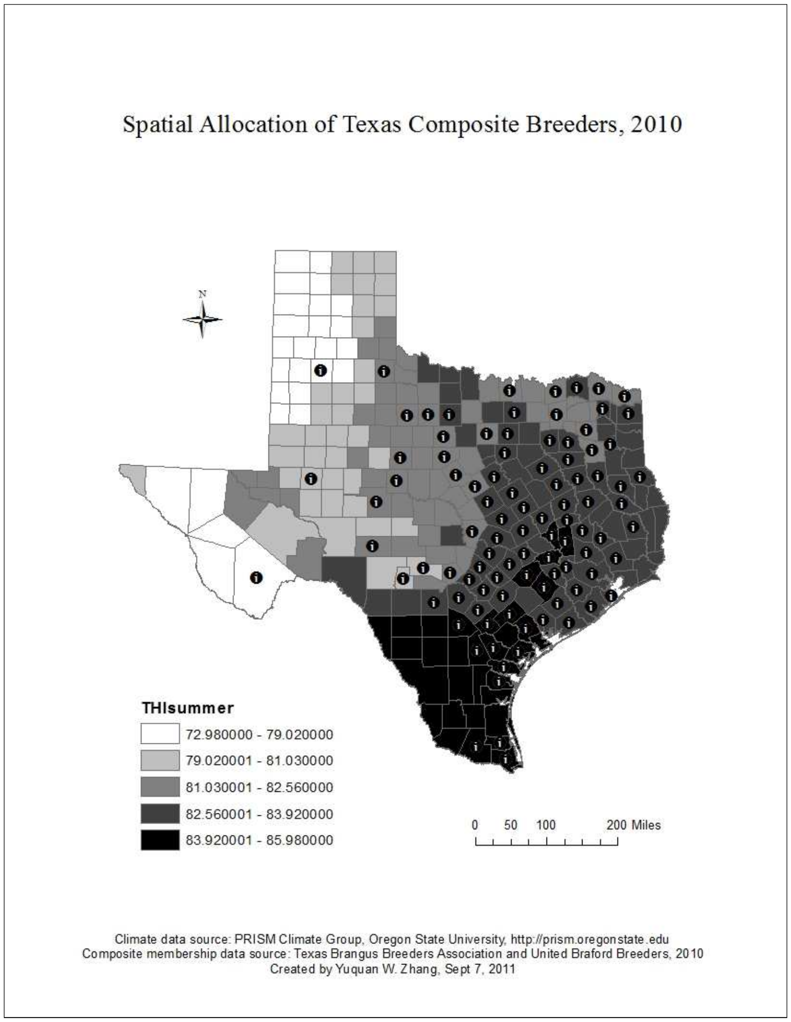


Figure IV-5 Spatial allocation of composite breeders against the background of summer heat stress (THIsummer) in Texas, 2010.

Figure IV-4 compares the spatial distributions of *Bos taurus* (including Angus and Hereford) and *Bos indicus* (Brahman) breeders. In the background, the darker the color, the more severe the summer heat stress is. As we can see on the left side, *Bos* *taurus* breeders spread across Texas, but not much in South Texas. *Bos indicus* breeders are shown to be concentrated in the hotter and humid coastal areas, suggesting that *Bos indicus* breeds may be more specialized for hot and humid costal environment.

Figure IV-5 presents the spatial allocation of breeders joining composite breed (including Brangus and Braford) associations. The geographic coverage of composite breeders appears to be between that of *Bos taurus* and *Bos indicus* breeders. And the majority of composite breeders are located in the coastal area and East Texas.

Overall, a review of the data above suggests that Texas is featured by great diversity in production conditions. For example, monthly spring precipitation could be as low as 7mm in a dry county and as high as 115mm in a wet county. Cattle inventory and pasture and rangeland acres also vary intensely across the counties. These pronounced variations in the data are expected to provide a good source for effects identification.

Model Results

Probit Model Estimation Results

Table IV-4 presents the probit regression results using grouped *Bos taurus*, composite, and *Bos indicus* binary choices as dependent variables. As indicated by the statistically significant *thisum* estimates in all three equations, summer heat stress places significant effects on breeder association membership – positive for *Bos indicus* and negative for *Bos taurus*. This meets the expectation that *Bos indicus* breeds are more common in the hot and humid environment in the Southwest region because of their known adaptability. In addition, summer heat stress imposes decreasing effects on membership in composite breeding associations, in smaller magnitude than that for *Bos taurus*, reflecting the general fact that composite breeds with *Bos indicus* traits are more adapted to heat stress than their *Bos taurus* parents. The effects of minimum winter temperature, *tminwin*, appear to be insignificant for *Bos taurus* and *Bos indicus* breeder membership but significantly positive for composite breeds. This implies that composite breeds are more likely to be adopted in counties with warmer winters, as composite breeds cattle typically do not wear hair coats thick enough to live through cold winters.

Comparing the summer heat stress and the winter condition, we find that summer effects are larger in magnitude than winter effects. Moreover, considering that a unit (°C) increase in summer temperature can lead to a greater-than-one unit increase in THI being used in the regression model, the influence of summer temperature thus could be even larger than what the *thisum* estimate indicates, further outweighing the influence of winter temperature.

Regarding forage conditions, spring precipitation, *prepspr*, is estimated to contribute positively to the *Bos taurus* breeder membership, suggesting that *Bos taurus* breeds are more likely to be raised in counties with greater spring precipitation that is essential for annual forage growth. On the other hand, *prepspr* estimates in Composite and *Bos indicus* equations are insignificant, implying the less forage demanding characteristic known for cattle with *Bos indicus* traits. Summer precipitation, *prepsum*, appears to have negative effects on *Bos taurus* membership, much likely due to the coastal humidity associated with high *prepsum* shown in Figure IV-3.

Table IV–4 Estimation Results for the *Bos taurus*, Composite, and *Bos indicus* Group (N=254).

	Bos taurus			*Composite*			*Bos indicus*		
Variable	Est.	Std. Err.	p-value	Est.	Std. Err.	p-value	Est.	Std. Err.	p-value
thisum	-0.301**	(0.131)	0.021	-0.206*	(0.123)	0.094	0.57**	(0.281)	0.043
tminwin	0.0509	(0.0733)	0.487	0.23***	(0.0694)	0.001	0.132	(0.143)	0.354
prepspr	0.0292***	(0.0113)	0.01	0.0111	(0.00758)	0.142	0.0234	(0.0151)	0.121
prepsum	-0.0334**	(0.0137)	0.015	-0.0133	(0.00898)	0.139	0.00603	(0.0134)	0.652
range	0.000458	(0.000338)	0.176	-0.00037	(0.000409)	0.362	-0.00078	(0.000552)	0.16
pasture	0.00223	(0.00375)	0.551	0.00396*	(0.00223)	0.076	0.00311	(0.00194)	0.109
hay	0.167	(0.189)	0.377	-0.155	(0.165)	0.347	0.197	(0.341)	0.564
topo	-0.0196	(0.0403)	0.627	0.037	(0.0319)	0.247	0.0888*	(0.0474)	0.061
taurusbsp	0.0202	(0.0949)	0.831	-0.0539	(0.0606)	0.374	0.164**	(0.0715)	0.022
taurusfmsp	0.021	(0.0796)	0.792	0.064	(0.0529)	0.226	-0.0412	(0.0356)	0.247
brangusbsp	-0.0743	(0.0781)	0.341	-0.125	(0.0772)	0.105	0.0576	(0.0984)	0.558
brangusfmsp	0.00407	(0.04)	0.919	0.0266	(0.0349)	0.446	-0.0477	(0.0353)	0.177
cattle	0.00542	(0.0039)	0.165	0.00294**	(0.00135)	0.029	0.00761**	(0.00372)	0.041
income	0.0763***	(0.0254)	0.003	0.0132	(0.0119)	0.265	0.0318**	(0.0135)	0.018
_cons	23.829**	(10.834)	0.028	18.471*	(10.092)	0.067	-57.04**	(24.427)	0.02
Correlation	Est.	Std. Err.	p-value						
ρ_{21}	0.197	(0.157)	0.21						
ρ_{31}	0.0989	(0.210)	0.637						
ρ_{32}	-0.0679	(0.168)	0.685						

Note: See Table IV-1 for variable definitions. Log pseudo likelihood = -253.233, Wald $\chi^2(42) = 182.75$, Probability > $\chi^2 = 0$.

The likelihood ratio test of $\rho_{21} = \rho_{31} = \rho_{32} = 0$, $\chi^2(3) = 1.132$, Probability > $\chi^2 = 0.769$.

* denotes significance at 10% level, ** at 5% level, and *** at 1% level.

In addition, counties with greater pasture land, or greater degree of management involved in grazing supply, are more likely to select composite breeds. Moreover, counties with larger topographic variation, measured by *topo*, tend to raise *Bos indicus* breeds. Recall that the slope of the rangeland can affect the access to forage.

The market conditions, represented by spring prices of *Bos taurus* and composite breeds, are in general not significant factors influencing breed association membership. However, the *Bos taurus* bull price, *taurusbsp*, has positive effects on *Bos indicus* membership, suggesting that the expensive investment associated with *Bos taurus* breeding can make breeders turn to other breeds, in particular raising the probability of choosing *Bos indicus* breeds.

Regarding county characteristics, the results suggest that counties having larger cattle inventories are more likely to select composite and *Bos indicus* breeds, with greater effects on the latter. Also, counties with relatively high household income level are more likely to choose *Bos taurus* and *Bos indicus* breeds.

The results above are based on aggregate *Bos taurus*, composite, and *Bos indicus* membership data and thus the picture of breed selection they provide is genetic-general. A more nuanced genetic-specific analysis using data on particular breeds from each major type is carried out. Tables IV-5 and IV-6 display genetic-specific results for two groups: the Angus, Brangus and Brahman group, and the Hereford, Braford and Brahman group, respectively. Note that Brangus is a composite breed with Angus and Brahman inheritance, and Braford a composite breed having Hereford and Brahman traits.

Table IV–5 Estimation Results for the Angus, Brangus, and Brahman Group (N=254).

	Angus			*Brangus*			*Brahman*		
Variable	Est.	Std. Err.	p-value	Est.	Std. Err.	p-value	Est.	Std. Err.	p-value
thisum	-0.185	(0.113)	0.101	0.0341	(0.15)	0.821	0.531**	(0.248)	0.032
tminwin	0.0242	(0.0684)	0.723	0.0343	(0.0865)	0.692	0.171	(0.117)	0.143
prepspr	0.0246**	(0.00971)	0.011	0.00751	(0.00817)	0.358	0.0241	(0.0165)	0.143
prepsum	-0.0203**	(0.00931)	0.029	-0.00838	(0.00967)	0.386	0.00406	(0.0115)	0.723
range	-0.00013	(0.0003)	0.659	-0.00128**	(0.000506)	0.012	-0.00095*	(0.000572)	0.096
pasture	0.00556	(0.00397)	0.162	0.00235	(0.00192)	0.222	0.00307	(0.00192)	0.111
hay	0.316*	(0.178)	0.075	-0.446**	(0.225)	0.047	-0.156	(0.375)	0.678
topo	0.0236	(0.0335)	0.482	0.0205	(0.0323)	0.526	0.0878*	(0.0494)	0.076
angusbsp	-0.158	(0.169)	0.351	-0.67***	(0.191)	0	-0.142	(0.174)	0.414
angusfmsp	-0.013	(0.0159)	0.416	0.0142	(0.0474)	0.764	-0.0475	(0.0311)	0.127
brangusbsp	-0.112	(0.0802)	0.161	-0.0978	(0.0749)	0.192	0.0118	(0.108)	0.913
brangusfmsp	0.0121	(0.045)	0.787	0.0375	(0.0361)	0.299	-0.0338	(0.0364)	0.354
cattle	0.00627**	(0.00312)	0.045	0.00463***	(0.00171)	0.007	0.00911*	(0.00466)	0.051
income	0.0372**	(0.0152)	0.014	0.0153	(0.0119)	0.199	0.0292**	(0.013)	0.024
_cons	20.034**	(9.256)	0.03	13.835	(13.064)	0.29	-44.311**	(21.161)	0.036
Correlation	Est.	Std. Err.	p-value						
ρ_{21}	0.401**	(0.195)	0.04						
ρ_{31}	0.806***	(0.150)	0						
ρ_{32}	-0.143	(0.157)	0.36						

Note: see Table IV-1 for variable definitions. Log pseudo likelihood = -275.206, Wald $\chi^2(42) = 251.26$, Probability > $\chi^2 = 0$.

The likelihood ratio test of $\rho_{21} = \rho_{31} = \rho_{32} = 0$, $\chi^2(3) = 6.975$, Probability > $\chi^2 = 0.0727$.

* denotes significance at 10% level, ** at 5% level, and *** at 1% level.

Table IV–6 Estimation Results for the Hereford, Braford, and Brahman Group (N=254).

	Hereford			*Braford*			*Brahman*		
Variable	Est.	Std. Err.	p-value	Est.	Std. Err.	p-value	Est.	Std. Err.	p-value
thisum	-0.147	(0.108)	0.173	-0.371*	(0.217)	0.088	0.509*	(0.306)	0.096
tminwin	0.0108	(0.055)	0.844	0.152*	(0.0892)	0.087	0.102	(0.146)	0.488
prepspr	0.00923	(0.00687)	0.179	0.0146*	(0.00781)	0.061	0.0279*	(0.0168)	0.097
prepsum	-0.0333***	(0.00904)	0	0.00222	(0.013)	0.865	0.00915	(0.0136)	0.502
range	0.000603**	(0.000268)	0.024	0.00039	(0.000626)	0.533	-0.00057	(0.000572)	0.321
pasture	0.00128	(0.00186)	0.492	0.00344	(0.00248)	0.166	0.00326*	(0.00197)	0.098
hay	0.0482	(0.156)	0.758	0.189	(0.168)	0.259	0.181	(0.327)	0.579
topo	-0.0328	(0.0284)	0.248	-0.0166	(0.0812)	0.838	0.0761*	(0.0445)	0.087
hfbsp	0.00526	(0.028)	0.851	-0.0197	(0.0222)	0.374	-0.0134	(0.0343)	0.696
hffmsp	0.0224	(0.0421)	0.594	0.0304	(0.0462)	0.51	0.126*	(0.0653)	0.053
brangusbsp	-0.0238	(0.0683)	0.727	-0.0664	(0.0835)	0.426	0.0982	(0.0965)	0.309
brangusfmsp	-0.00333	(0.0406)	0.935	0.0768*	(0.042)	0.068	-0.0555	(0.0347)	0.11
cattle	0.000261	(0.00154)	0.866	0.00128	(0.00161)	0.426	0.00655	(0.00424)	0.122
income	0.0324***	(0.0124)	0.009	-0.0112	(0.0159)	0.482	0.0189	(0.0137)	0.169
_cons	12.399	(9.04)	0.17	26.378	(17.711)	0.136	-52.734**	(26.24)	0.044
Correlation	Est.	Std. Err.	p-value						
ρ_{21}	-0.294	(0.204)	0.15						
ρ_{31}	-0.067	(0.165)	0.685						
ρ_{32}	-0.165	(0.322)	0.61						

Note: See Table IV-1 for variable definitions. Log pseudo likelihood = - 242.743, Wald $\chi^2(42) = 189.58$, Probability > $\chi^2 = 0$.

For the likelihood ratio test of $\rho_{21} = \rho_{31} = \rho_{32} = 0$, $\chi^2(3) = 1.678$, Probability > $\chi^2 = 0.642$.

* denotes significance at 10% level, ** at 5% level, and *** at 1% level.

Table IV-5 shows that compared to the *thisum* estimate for *Bos taurus* in Table IV-4, the effects of summer heat stress become less significant on Angus. And still, spring precipitation is found to contribute positively to the Angus membership whereas summer precipitation does the opposite. For forage conditions, counties having larger rangeland – the natural grazing supply – are less likely to select breeds with *Bos indicus* influence, as suggested by the *range* estimates in the Brangus and Brahman equations. Hay yield (*hay*) appears to be a positive factor influencing the Angus membership, reflecting the relatively high forage requirements associated with Angus. On the other hand, Brangus is less demanding in the aspect of hay productivity.

Regarding the market conditions, higher Angus bull prices (*angusbsp*) are found to decrease the Brangus membership, implying that expensive investment in Angus bulls – possibly for cross breeding purposes – negative influences the selection of Brangus. As for county characteristics, different from the results in Table IV-4, counties with larger cattle inventories are found to be more likely to select Angus. This may indicate a popular commercial use of Angus in the feedlot area.

Furthermore, the significant ρ estimates for the Angus-related equations suggest that it's more efficient to estimate the three equations jointly than separately.

Turning to Table IV-6 presenting the results for Hereford, Braford and Brahman group, we find that both summer heat stress and winter condition have significant effects on the Braford membership, similar to results in Table IV-4. These noteworthy estimates of response to climate conditions in choosing Braford are, however, very likely a result of the sparse data on Braford membership in Texas. For Hereford – a kind of *Bos taurus* breed, again, summer precipitation decreases the likelihood of Hereford membership.

Regarding the forage conditions, larger rangeland is found to contribute positively to the Hereford breeder incidence – a duality result corresponding to the *range* estimates in Table IV-5 showing that counties with larger rangeland are less likely to choose Brangus and Brahman breeds. Meanwhile, larger pasture land indicating more management in grazing supply increases the Brahman breeder incidence. In addition, as have appeared in Tables IV-4 and IV-5, topographic variation increases the likelihood of Brahman membership.

As for market conditions, Hereford female prices are estimated to have positive effects on the Brahman breeder incidence, implying an existence of substitutability between Hereford and Brahman that is driven by economic factors. This indicates that, as suggested in Table IV-4 also, there is a price-based trade-off between *Bos taurus* and *Bos indicus* breeds faced by cow-calf producers along with the price versus production trade-off.

Marginal Effects of Summer Heat Stress

The marginal effects of summer heat stress on marginal incidence probabilities of *Bos taurus*, composite, and *Bos indicus* breeder membership are calculated by scaling the marginal success probabilities with *thisum* coefficient estimates for each equation.

As summarized in Table IV-7, on average, a marginal increase in summer heat stress will reduce the marginal incidence rate of *Bos taurus* membership by over 26%.

The negative effects on composite membership are lesser – about 8%. On the other hand, a marginal increase in summer heat stress can raise the marginal incidence rate of *Bos indicus* membership by about 10%. Thus, when climate gets warmer, breeders initially adopting *Bos taurus* and composite breeds may have to turn to *Bos indicus* breeds.

Table IV–7 Marginal Effects of Summer Heat Stress on Marginal Incidence Probability of Breeder Membership.

	Mean	*Std. Dev.*
Bos taurus	-0.265	0.051
Composite	-0.079	0.058
Bos indicus	0.097	0.128

Figure IV-6 presents the spatial pattern of marginal effects of summer heat stress on *Bos indicus* breeder membership, as well as the current map of *Bos indicus* breeders. Note that the darker the color, the higher the positive marginal effects are. As we see, a marginal increment in summer heat stress will further increase the probability of adopting *Bos indicus* in the coastal area. The positive marginal effects are smaller in East Texas however.

The spatial pattern of marginal effects of summer heat stress on *Bos taurus* and composite breeds are shown in Figure IV-7. The maps of 2010 *Bos taurus* and composite breeders are included as well. Note that this time, the darker the color, the greater the negative effects. As we can see on the left, as summer heat stress gets more severe, the incidence of *Bos taurus* membership in most counties decreases by at least 20% - and most current *Bos taurus* breeding sites will be affected. For composite breeds, the rise in summer heat stress decreases the marginal probability by at least 9% in much of the East Texas. And again, many of the current composite breeds breeding sites will be affected.

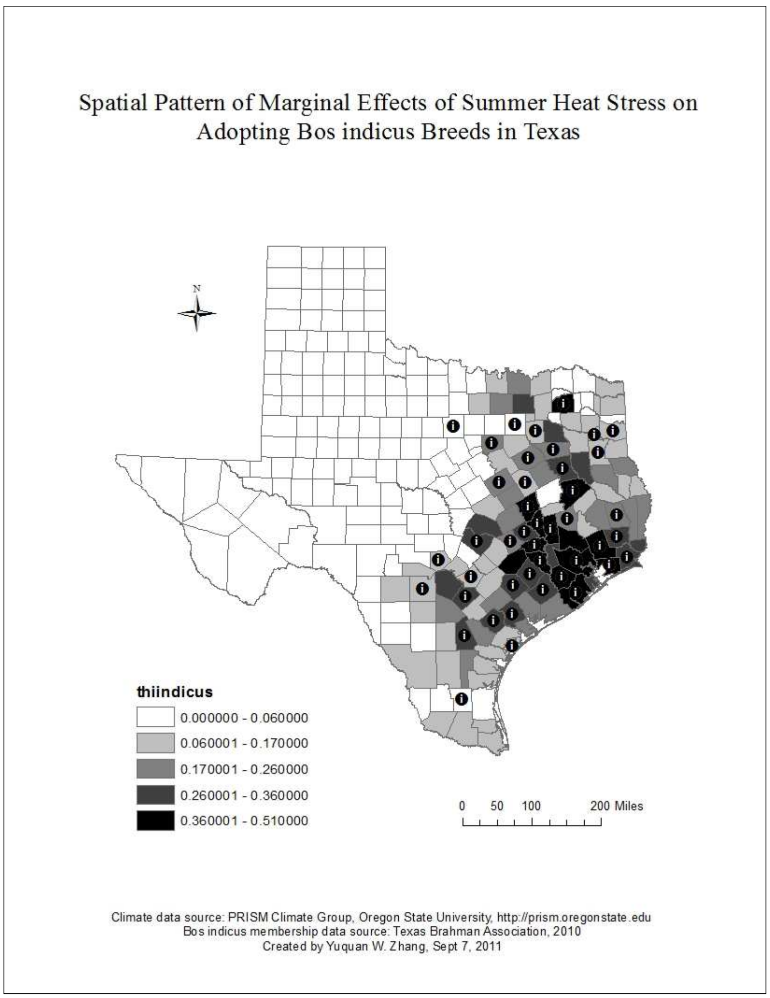


Figure IV-6 Spatial pattern of marginal effects of summer heat stress on *Bos indicus* breeder membership in Texas.

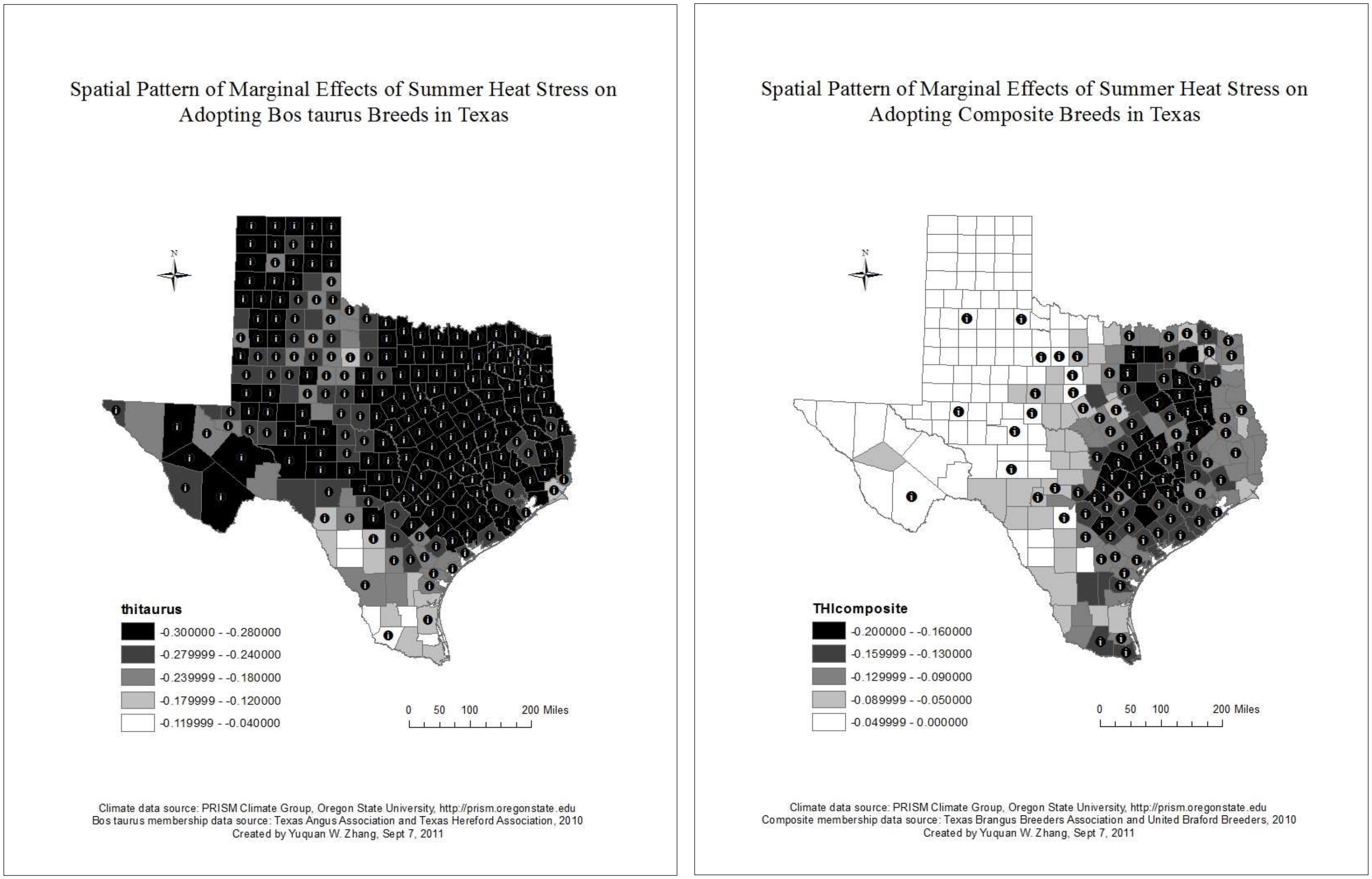


Figure IV-7 Spatial pattern of marginal effects of summer heat stress on *Bos taurus* (left) and composite (right) breeder membership in Texas.

Conclusions and Discussion

Breed has a significant impact on the production efficiency of and the economic returns to breeding activities for cow-calf producers. Cattle of different breeds differ in reproductive performance, weaning and mature weight, carcass quality, and adaptive ability to various environments among many other aspects. In particular, *Bos indicus* breeds or composite breeds with *Bos indicus* traits are often selected in the South U.S. principally because of their heat-tolerance characteristic (Hawkes, Lillywhite and Simonsen 2008). Under future climate change – projected by IPCC WGI (2007) as inevitable, further selection for heat-tolerant breeds may be necessary (Hoffmann 2010).

This research conducts an analysis of the spatial allocation of breeders raising a variety of breeds in Texas, focusing on Angus, Hereford, Brangus, Braford, and Brahman to investigate how climate factors influence the decision making of cattle breeds selection at cow-calf operation level. A multivariate probit model is employed for the purpose of this study, since the breed options for a given location are not necessarily mutually exclusive.

The estimation results suggest that summer heat stress, measured by temperature-heat index, suppresses the incidence probability of breeders that raise *Bos taurus* and composite breeds with *Bos indicus* influence, especially the former one. On the other hand, summer heat stress increases the likelihood of breeders raising *Bos indicus* breeds. Spring precipitation that is essential for annual forage growth is found to be supportive for selecting *Bos taurus*.

The natural and managed grazing supplies, represented by rangeland acreage and pasture acreage respectively, are in general found to have minimal influence on breed association membership. Nonetheless, the breed-specific estimation results suggest that counties with larger areas of rangeland are less likely to have larger numbers of breeders with composite breeds and *Bos indicus* breeds but on the other hand may be more likely to have more with *Bos taurus* breeds. In addition, greater topographic variation that affects the access to forage increases the likelihood of *Bos indicus* membership.

The market condition factors – represented by spring bull and female prices – are generally found to be insignificant for breed selection, corresponding to Hammack (2010a) in that the decision-making of breed selection rests more upon production conditions. The exception is that the *Bos taurus* bull price is found to have positive effects on the *Bos indicus* membership. Further, the breed-specific estimation results show that the female price of some *Bos taurus* breed may increase the likelihood of *Bos indicus* membership. Therefore, in addition to the typical trade-off between market-desirable features and production-suitable traits faced by cow-calf producers, there is also a price-driven trade-off or substitution between *Bos taurus* and *Bos indicus* breeds.

Lastly, the marginal effects of summer heat stress on *Bos taurus* and composite breeder membership are estimated to be negative, with the former one being affected more (-26.5% on average) than the latter one (-7.9% on average). On the other hand, the marginal effects of summer heat stress on *Bos indicus* membership are positive (9.7% on average).

To repeat, the results confirm that summer climate is an important factor for the incidence of cow-calf producers that belong to breed associations for heat tolerant breeds, and its effects outweigh winter climate. Also, spring precipitation that benefits forage growth increases *Bos taurus* breed association membership. In addition, a price-driven trade-off between *Bos taurus* and *Bos indicus* breed association membership may exist along with the typical market versus production trade-off.

The research presented in this essay, however, is subject to several limitations, largely due to the paucity of data. First we could not obtain data on population by breed so used breed association membership as a proxy, which may be subject to the problem of underreporting. Second we could not get all the climate data we might want. For example, a comprehensive cold index for winter, rather than the minimum temperature, could help capture the winter climate effects more accurately. Third the physical data were somewhat lacking. For example, an augmentation of county-level soil information of rangeland and pasture land to the model can help the model better represent forage conditions. Fourth the market data were limiting. In particular, a more complete collection of breed-specific price data may improve the quality of the estimation results. Lastly, but not least, a time-series analysis of breed adoption against climate factors may be desirable for future research – recall that this essay uses cross-section data on 2010 for analysis.

CHAPTER V

SUMMARY

Propelled by energy security concerns and high energy prices, U.S. biofuels production has expanded rapidly since the early 2000s. The RFS2 mandates require that by 2022, 36 BGY of renewable fuels are to be produced – among which 21 BGY will be derived from cellulosic and other advanced sources. This biofuels production activity contributes to climate change mitigation also – by reducing GHG emissions associated with using fossil fuel liquids.

Though mitigation efforts such as biofuels production are being made, climate change is however inevitable according to IPCC WGI (2007). The U.S. agricultural sector has shown by history that it adapts to variability in climate, soil, and market conditions among many other factors. Under future climate change, the U.S. agricultural sector will thus continue to change to adapt to new environments.

This dissertation investigated various aspects of the effects of climate change and mitigation on U.S. agriculture, reporting on welfare, price and production, and land use changes at national level. Also, this dissertation took cattle breeds selection in Texas as a case study to gain a regional insight for developing climate change adaptation strategies.

Specifically, this dissertation examined:

- the implications of introducing high-yielding energy sorghum for RFS2 purposes on U.S. agriculture, in terms of biofuel feedstock mix, agricultural market equilibriums, and GHG mitigation performance;

- the effects of RFS2 and projected climate change on U.S. agriculture and their mutual effects on each other;
- the extent to which long-term climate factors affect Texas cattle breed selection.

Key findings for the investigations mentioned above are summarized below.

In Chapter II, high-yielding energy sorghum is projected to produce large amounts of cellulosic ethanol under RFS2 economically, meanwhile occupying less cropland for its production, compared to a no energy sorghum scenario in which switchgrass takes the lead. Also, with high-yielding energy sorghum, price alleviation, restored production and export level for agricultural commodities would follow except for grain sorghum due to regionally concentrated cropland use competition between grain and energy sorghum. In addition, enhanced GHG mitigation does not necessarily follow. These results indicate that the advantage of introducing high-yielding energy crops under RFS2 largely lies in ameliorating land use competition and market distortions, but not improving agricultural GHG mitigation performance.

In Chapter III, the effects of RFS2 are found to be on the opposite of the effects of climate change (with autonomous adaptation) on U.S. agriculture, as measured by changes in agricultural welfare, commodity price, production and export Fisher indices, as well as cropland usage and land use change. In particular, climate change is found to make it easier for the U.S. agricultural sector to support a large-scale biofuel program. Also, it induces greater use of crop residues and non-switchgrass dedicated energy crops for RFS2 purposes.

In Chapter IV, summer heat stress – measured by temperature-heat index – is found to be a significant factor for breed association membership in Texas. And its marginal effects on breed association membership are estimated to be positive for *Bos indicus*, and negative for *Bos taurus* and composite breeds. Winter climate, on the other hand, is in general not a significant factor. Spring precipitation that benefits annual forage growth is found to have positive effects on *Bos taurus* association membership. Also, counties with greater topographic variation are more likely to select *Bos indicus*. In addition, a price-driven trade-off between *Bos taurus* and *Bos indicus* may exist along with the typical trade-off between market and production conditions.

In presenting the results above, several limitations must be noted. Both Chapters II and III have utilized the agricultural component of FASOMGHG – thereupon by not allowing exchanges between the agricultural and forestry sectors, the results may be understatements or overstatements of the true outcomes. For Chapter II that examines RFS2 impacts, the absence of the forestry sector may imply an overstatement of the price effects of RFS2, since a potential land supply from the forestry sector for agricultural use is disabled. For Chapter III that explores the effects of RFS2 and climate change, the consequences of the absent forestry sector in the model are however unclear. Besides, for Chapter III, the climate feedbacks of GHG mitigation efforts may need to be considered. As for Chapter IV that analyzes the spatial allocation of Texas breeders, the paucity of data limits the interpretive power of the estimates.

For future research, given the expandability of FASOMGHG (Adams et al. 2005), more potential high-yielding energy crops may be incorporated into the model for

Chapter II, if data are available. For Chapter III, it may be desirable to use data derived from region-specific GCMs to obtain a more accurate picture of climate change effects, as Adams, McCarl and Mearns (2003) has noted the importance of spatial resolution for climate change studies. Also, the data on climate change effects derived under RFS2-dependant climate change scenarios would be desirable for use. Lastly, but not least, for Chapter IV, an inter-temporal analysis of cattle breed selection against climate factors may help to augment the findings in this research.

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